WATER QUALITY MONITORING PLAN

PHASE II REPORT

GRYN

Greater Yellowstone Inventory & Monitoring Network
Bighorn Canyon NRA, Grand Teton NP, Yellowstone NP

January 2004

Executive Summary

The Greater Yellowstone Inventory and Monitoring Network (GRYN) is one of 32 National Park Service (NPS) Inventory and Monitoring (I&M) Networks created to provide oversight, planning and consistency in monitoring the long-term health of the nation's parks. The parks of the GRYN include Yellowstone National Park (YELL), Grand Teton National Park and the John D. Rockefeller, Jr. Memorial Parkway (collectively referred to as GRTE), and Bighorn Canyon National Recreation Area (BICA). The GRYN Water Quality Monitoring Plan Phase II Report summarizes the activities undertaken to select and prioritize vital signs used for monitoring the state of the parks' water quality. It represents the second phase of a 3-phase planning process: Phase I consisted of the compilation of background data on the GRYN parks and conceptual modeling; Phase II (this document) describes those activities completed in Phase I and the selection and prioritization of vital signs; and Phase III will include the entire scope of information in Phases I and II as well as further identifying specific monitoring objectives, sampling designs and protocols, and data management and analysis procedures. This Water Quality Monitoring Plan includes not only needs identified through the Vital Signs Monitoring Program (VSM), but also those that have been mandated by federal (Environmental Protection Agency and NPS) and state (Montana and Wyoming Departments of Environmental Quality – DEQ) regulations.

The maintenance and monitoring of water quality is addressed in a variety of federal legislation and state guidelines including the National Park Service Organic Act, the National Parks Omnibus Act, the Government Performance and Results Act, the Clean Water Act and Montana and Wyoming DEQ regulations. The GRYN includes a wealth of surface water resources ranging in quality from impaired (303[d] listed waters) to pristine (Outstanding Natural Resource Waters). The water resources of GRYN provide public recreational opportunities, plant and wildlife habitat, and unique scenic vistas within the parks, while these waters also provide inputs to downstream habitats and end-users. Management issues and stressors relating to water quality in the GRYN include external as well as internal factors. These include altered hydrology, mining, agriculture, recreation, grazing of both livestock and native ungulates, erosion, sewage treatment plant operations, stormwater runoff events, climate change, and atmospheric deposition. Water quality monitoring in various forms has been conducted in the GRYN parks for over 50 years. The USGS operates and maintains several surface water stations within or near each GRYN park, collecting both physical and chemical data. Each park performs some water quality monitoring as part of their annual operations. Due to the myriad and complexity of issues relating to water quality, and to the variety of historic and ongoing research and monitoring activities, the GRYN formed a Water Quality Working Group (WQWG) in 2002. The WQWG identified water quality issues in each park, assessed the current monitoring occurring in the parks, and provided oversight to a contractor who researched and summarized current and historic water quality projects within the parks.

The goals of the water quality monitoring program are based on state and federal requirements and on the results of the VSM planning process. The desired future condition for surface waters in GRTE and YELL is to preserve current pristine and unimpaired conditions, and to restore water quality to standards in currently impaired waters. In BICA

the desired future condition is to prevent further degradation of water quality. The achievement of these goals will require cooperation with landowners and agencies outside of, as well as within, the parks. Monitoring strategies will be designed to provide resource managers with information relevant to achieving the desired future condition for surface waters, and to assessing trends in water quality within the parks. The GRYN has undertaken an extensive process to select a defensible list of vital signs. Of the 44 vital signs selected for monitoring, 10 (directly related to water quality) were identified by the GRYN program manager to be included in this document. These ten vital signs and their proposed measurements were associated with GRYN conceptual models. Monitoring objectives for regulatory purposes were developed. Monitoring objectives for other than regulatory issues will be developed in Phase III of the planning process. Monitoring protocols will be designed to address multiple water quality issues using established, as well as new, techniques that can be analyzed to assess current conditions and trends.

Acknowledgements

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I. The Planning Process

A. Introduction

National Park managers are directed by federal law and NPS policies and guidance to know the status and trends in the condition of natural resources under their stewardship in order to fulfill the NPS mission of conserving parks unimpaired (NPS Organic Act, 1916). The NPS has implemented a strategy designed to standardize natural resource inventory and monitoring on a programmatic basis throughout the agency. This effort has been undertaken to ensure that approximately 270 park units, with significant natural resources, possess the resource information needed for effective, science-based managerial decision-making and resource protection. To increase efficiency and consistency among parks, each park has been assigned to one of 32 networks. The national strategy consists of a framework having three major components:

1) completion of basic resource inventories upon which monitoring efforts can be based;
2) creation of experimental Prototype Monitoring Programs to evaluate alternative monitoring designs and strategies; and
3) implementation of operational monitoring of critical parameters (i.e. "vital signs") in all natural resource parks.

To guide the vital signs monitoring program, all 32 park networks address the following five goals of vital signs monitoring as they plan, design, and implement integrated natural resource monitoring:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

The recommended sequence of steps involved in designing an integrated monitoring program for a network is described in the Recommended Approach for Developing a Network Monitoring Program (NPS 2003a). These seven steps are incorporated into a 3-phase planning and design process that has been established for the monitoring program. Phase 1 of the process involves defining goals and objectives; beginning the process of identifying, evaluating and synthesizing existing data; developing draft conceptual models; and completing other background work that must be done before the initial selection of ecological indicators. Each network is required to document these tasks in a Phase 1 Report (a first draft of the chapters of the final monitoring plan that present the Introduction/Background and Conceptual Models), which is then peer reviewed and approved at the regional level before the network proceeds to the next phase. Phase 2 of the planning and design effort involves prioritizing and selecting vital signs and developing specific monitoring objectives for each that will be included in the network's initial integrated monitoring program. The Phase 2 Report for the GRYN can be found on-line (GRYN 2003). Phase 3 entails the detailed design work needed to implement monitoring, including the development of sampling protocols, a statistical sampling design, a plan for data management and analysis, and details on the type and content of various products of the monitoring effort such as reports and websites.

Networks have been given the option of producing a single, integrated monitoring plan, or a separate document for the water quality monitoring component that follows the detailed guidance developed by the NPS-Water Resources Division (NPS-WRD). This guidance is presented in five parts (NPS 2003b). The end product is a detailed water quality monitoring plan. The plan is required to include:

- a description of the major/most significant water bodies identified in the Network;
- locations of the monitoring stations to be established;
- parameters to be measured at each station (including the data objectives of that monitoring);
- the sampling protocols to be followed (may vary by state);
- the quality assurance and quality control measures;
- and any statistical analysis of the data that will be undertaken.

The GRYN has selected to produce a separate Phase 2 Report for the water quality monitoring plan. Sections B-E (below) detail the planning steps taken by the GRYN to produce this plan.

Target Audience

Appreciation of the scenic beauty and enjoyment of recreational activities associated with water resources are central themes in each of the GRYN parks. Park managers are keenly interested in the status of these resources. The results of a well-designed, long term water quality monitoring program can provide information for management decisions, and provide early warnings of ecosystem degradation (Noon et al. 1999). The most commonly stated objective of a monitoring program is to enable managers to make better informed decisions (Silsbee and Peterson 1991). A related objective is to use monitoring information to convince others to make decisions benefiting parks (Croze 1982). The intended audiences for the results of a monitoring program are summarized in Table 1.

Table 1. Summary of programmatic monitoring objectives and intended audience for resulting information (adapted from Silsbee and Peterson, 1991)

OBJECTIVES	AUDIENCE
Inform internal decision makers	NPS managers
Influence external decision makers	External decision makers
Satisfy legal requirements	Variable
Maintain familiarity with resources	NPS personnel
Provide for better understanding of resources	Scientists and NPS personnel
Provide background information	Scientists, NPS personnel, visitors
Provide early warning of global or regional problems	External decision makers
Provide background data for exploited areas	External decision makers and NPS personnel

B. Summarize existing data and understanding.

In 2001, the GRYN began the process of data mining and database review to determine the status of active and historic water quality monitoring within Network parks. This was accomplished through a combination of activities, including a review of Dataset Catalog, NatureBib, park-specific data mining efforts, and a questionnaire (summarized in Appendix A).

Dr. Scott Woods (University of Montana, College of Forestry and Conservation) was then asked to conduct a preliminary review of existing water quality data for the three parks. As part of this review process, historical water quality data for the GRYN were assessed to: 1) review the data for their utility in determining the status and trends in water quality; 2) determine the status and trends and the range of variability in water quality; 3) identify and prioritize water quality monitoring needs in accordance with the goals of the Vital Signs monitoring program; and 4) identify pollutants that exceed water quality standards. To facilitate data analysis, and prior to entry into a database, each data record was assigned to one of thirteen parameter groups:

- Alkalinity
- pH
- Conductivity
- Dissolved Oxygen
- Temperature
- Flow
- Toxic Elements
- Clarity/Turbidity
- Nitrate/Nitrogen
- Phosphate/Phosphorus
- Chlorophyll
- Sulfate
- Bacteria

These groups represent the major parameters identified as those that all parks must have for "key" waterbodies (NPS 1993).

Each record in the database was compared to state and federal water quality standards, so that historical and existing water quality problems could be identified. Wyoming state standards were used for the comparisons because they are generally more comprehensive and more stringent than Montana standards. The standard used for each comparison was the most stringent of a variety of Environmental Protection Agency (EPA) and state water-quality criteria (refer to Woods and Corbin, 2003a, b, & c, for a more detailed explanation).

The comparison of historical data with water quality standards revealed numerous water quality standard exceedances for each park (Appendix B). It is important to note that an exceedance of water quality standards does not necessarily imply “dirty” or impaired water. For instance, in the thermally influenced waters of YELL, state or EPA standards may not be applicable. Also, some of the historical data result from one-time research projects and may not be reliable.

C. Prepare for and hold a scoping workshop. Hold meetings to decide on priorities and implementation approaches.

In June of 2001 the GRYN held a meeting to identify park sources and points of contact for current and historic water quality data water quality issues. Subsequent meetings (summarized in Appendix C) addressed a variety of issues, including the formalization of a Water Quality Work Group (WQWG).

D. Draft the monitoring strategy.

One result of the meetings/discussions of the WQWG is the following list of general recommendations that have been used to help guide the development of water quality monitoring objectives:

1. *Use USGS protocols for chemistry and EPA protocols for biology/bacteria*
2. *Tailor monitoring to issues/themes in each park*
3. *Develop strategies based on watershed boundaries and use hydrology/geology as the primary basis for sample site selection*
4. *Consider using in-situ sensors*
5. *Conduct an initial round of high frequency sampling*
6. *Relate measurements to discharge*

The WQWG began a process of developing monitoring objectives, or “questions to be answered”, for each of the three GRYN parks. These objectives included those for regulatory monitoring, as well as park specific vital signs monitoring. The objectives developed were intended to serve as the basis for the water quality monitoring plan for the GRYN. Additionally, the WQWG planned to evaluate existing monitoring protocols (USGS, EPA, WY-DEQ, MT-DEQ, and others) for their applicability to GRYN selected vital signs.

Part of the monitoring strategy must include plans for data management. Per national guidance, water quality related monitoring data will utilize the NPS-WRD database template, and ultimately be uploaded to EPA's storage and retrieval (STORET) database.

E. Have the monitoring strategy reviewed and approved.

The plans for water quality vital signs monitoring will be subject to critical peer review. Suggestions for peer reviewers include individuals from agencies such as the USGS and the EPA, as well as local experts and University-based scientists.

II. Introduction and Background

A. Background

The need to monitor natural resources has been established through a variety of federal legislation and NPS policy and guidance. The following summarizes the legislation and policy related specifically to the maintenance and monitoring of water quality.

Federal Legislation

Pertinent federal legislation includes the National Park Service Organic Act of 1916 and the National Parks Omnibus Management Act of 1998 (NPS 1998). In 2001, NPS Management Policies were updated to include the statement that "*Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions*" (NPS 2000).

Water resources are further protected under the guidance of the Clean Water Act (CWA), or the Federal Water Pollution Control Act, as it is more properly known. The CWA was passed in 1972 to offer Federal protection to the country's waterways. The Clean Water Act's purpose is to stop pollutants from being discharged into waterways and to maintain water quality to provide a safe environment for fishing and swimming.

Section 303(d) of the CWA requires states to assess the condition of their waters to determine where water quality is impaired or threatened. The result of this review is the 303(d) list, which must be submitted to the EPA every other year. Section 303(d) also requires states to prioritize and target water bodies on their list for development of water quality improvement strategies (i.e. Total Maximum Daily Loads or TMDLs), and to develop such strategies for impaired and threatened waters. States must also develop, adopt and implement an antidegradation policy as a key portion of their water quality standards. Both Wyoming and Montana have 2002 303(d) listings for surface waters within the GRYN (Wyoming DEQ 2002a; Montana DEQ 2002a).

Waters of exceptional ecological significance have been designated as Outstanding Natural Resource Waters (ONRWs) by the EPA. These waters are thought to be the highest quality waters of the United States. The U. S. EPA Water Quality Standards Handbook (1994b) provides ONRWs with the highest level of protection. Early on in the planning process for the Inventory and Monitoring Program, the NPS-WRD reviewed current water quality standards and regulations for all states represented by the 12 networks that were funded in

FY 01 and 02, including the GRYN. All of the waters in GRTE and YELL have been identified by NPS-WRD as exceptional or outstanding national or state resource waters (NPS 2003b. wqPartA, Table 2).

A discussion of the waterbodies which have been identified by the states as 303(d) listed waters and Outstanding Natural Resource Waters, within the GRYN's boundaries, appears further on in this section.

NPS Guidance

National Park Service Mission

The National Park Service Mission Statement proposes to preserve "unimpaired the natural and cultural resources of the national park system." (NPS Organic Act, 1916) Several principles were developed to guide the attainment of this mission, the most relevant of which (as related to water quality and vital signs monitoring) are:

- Science and Research: Applying scientific information to park management decisions to preserve park resources
- Environmental Leadership: Complying with all environmental laws and applying the highest standards of environmental stewardship to our own operations.

Government Performance and Results Act

The Government Performance and Results Act (GPRA) of 1993 requires agencies to submit annual performance plans to Congress with their fiscal year budget request and to prepare an annual performance report at the end of each fiscal year on how well they met their goals. The Department of the Interior (DOI) established five broad goals that encompass its major responsibilities. These are:

1) Protect the environment and preserve our nation's natural and cultural resources
2) Provide recreation for America
3) Manage natural resources for a healthy environment and a strong economy
4) Provide science for a changing world
5) Meet our trust responsibilities to Indian tribes and our commitments to island communities.

The National Park Service's Strategic Plan follows the requirements of GPRA, and is consistent with these broad DOI goals. The NPS has four goal categories (Park Resources, Park Visitors, External Partnership Programs, and Organizational Effectiveness) and three kinds of Servicewide goals (Mission Goals that continue indefinitely, Long-term Goals that generally last five years, and Annual Goals of only 1-year duration). NPS Mission Goals Ia and Ib relate directly to the vital signs water quality monitoring program. Strategic plans for the GRYN parks can be found on the internet at <http://im.den.nps.gov/rg_GpraDR.cfm>.

Mission Goal Ia states that natural and cultural resources and associated values are protected, restored and maintained in good condition and managed within their broader ecosystem and cultural context. Long Term Goal Ia4 is directly related to water quality, and requires that 85% of park units have unimpaired water quality. The Annual Performance

Goal (for FY03) requires that by September 30, 2003, 65% of parks have unimpaired water quality.

Goal Description: The quality of water in the natural environment is a critical indicator of the health of that environment. Improved water quality enhances plant and animal species in the parks and can play a significant role in the safe recreational use of park resources. Almost 300 units of the National Park Service contain rivers, lakes, reservoirs, streams, springs, and wetlands, including 18 national riverways, 14 national seashores and lakeshores, and 12 parks containing major reservoirs.

Strategies: Through the water quality portion of the Natural Resources Challenge, the NPS is initiating the design phase for monitoring programs that will allow parks to detect and assess changes in the condition of some waters and evaluate threats resulting from an array of sources and activities (both external and internal). A water resources program assists parks in providing specialized water quality inventories and monitoring, water resources data management, and geographic information system (GIS) applications. In addition, the NPS has developed a partnership with the U.S. Geological Survey to acquire water quality data to support objective periodic assessments of the status of water quality in the national park system. While "unimpaired water" is still being defined and metrics being developed for natural areas, NPS is using state defined water quality standards as a means for developing a baseline for park water quality.

In their strategic plans, each GRYN park states the goal of having or maintaining unimpaired water quality by September 30, 2005. BICA's Strategic Plan includes the following caveat:

"Because of the extremely large size of the Bighorn/Wind River drainage (some 18,000 square miles) it is impossible for Bighorn Canyon to control whether or not the lake's waters are listed on the State's Section 303(d) list. Control of this type of problem is beyond the authority of the National Park Service. Bighorn Canyon will continue to be a strong advocate of high water quality standards for all waters entering Bighorn Lake, however the actual responsibility for the setting and enforcement of water quality standards lies with the State of Wyoming. Another water quality issue that faces the park is the issue of sedimentation in the southern end of the reservoir. The Soil Conservation Service estimated in 1994 that 3,600 metric tons (4,000 tons) per day of sediment enters the southern end of the reservoir. The identified causes of this sediment are, according to the Soil Conservation Service, erosion of streambanks, flows returned to the river after cropland irrigation, erosion from croplands due to irrigation practices, and erosion from rangeland. Once again there is little that the park can do that directly affects this problem except continue to be an advocate of high water quality standards and improvement in irrigation practices in the upstream basins from the park." (NPS-IMR 2003)

Bighorn Canyon advocates sediment control as part of any state-initiated TMDL process.

Mission Goal Ib states that the National Park Service contributes to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on adequate scholarly and scientific information. The Long Term Goal Ib3 relates directly to the identification of Vital Signs, and requires that 80% of parks with significant natural resources have identified their vital signs for resource monitoring.

> Vital signs indicate key ecological processes that collectively show ecosystem health. They include keystone species, keystone habitats or key processes such as nutrient cycling or hydrologic regimes. The Annual Performance Goal (for FY03) requires that by September 30, 2003, 40% of parks with significant natural resources have identified their vital signs for natural resource monitoring.
>
> *Goal Description:* A clear and simple method to identify the health of the resources is needed. The preservation of healthy parks depends on acquiring timely and accurate information about the condition of the natural resources, monitoring how conditions change over time, and acting on that information with confidence. Achievement of this goal will provide a sound scientific foundation for measuring NPS performance in natural resource stewardship.
>
> *Strategies:* Vital signs will be identified through fact-finding workshops involving park staff and experts from inside and outside the NPS who are knowledgeable about parks' natural resources and ecosystems. The identification of vital signs satisfies Goal Ib3. The development of a monitoring program and actual vital signs monitoring will provide the information identified in Goal Ib, which will provide the basis for sound and scientifically-based decision-making in the future.

In their strategic plans, each GRYN park states the goal of identifying its vital signs for natural resource monitoring by September 30, 2005.

Park Specific Guidance

<u>Bighorn Canyon NRA</u>

In 1996, a Water Resources Management Plan for BICA was published (Jacobs et al. 1996), providing direction for future water related research.

<u>Grand Teton NP</u>

In 1998, a Water Resources Scoping report was published for GRTE (Mott 1998) which described the hydrologic and related physical processes, how these processes interact with biological resources, and issues potentially affecting water resources in and around Grand Teton National Park.

<u>Yellowstone NP</u>

At the present time, Yellowstone National Park does not have either a water resources scoping report or a water resources management plan in place. Management/monitoring of park waters is guided by general and resource management plans, along with individual project funding.

Bighorn Canyon National Recreation Area

The water resources of BICA are diverse. They include Bighorn Lake (the reservoir created by Yellowtail Dam in 1966), 5-10 miles of the Bighorn River and 2-3 miles of the Shoshone River above the pool of Bighorn Lake, several small ponds constructed in the Yellowtail Wildlife Habitat Management Area and in other park locations for wildlife and water management, the extreme lower reaches of several small streams that flow into the east and west sides of Bighorn Lake, a small number of seeps and springs primarily located at the base of the Pryor Mountains in the western portion of the park, and the wetland and riparian areas associated with these systems (Jacobs et al. 1996).

The Bighorn River and its tributaries are part of the Bighorn/Wind River Basin of the Missouri River Basin. Most of the park is contained within the Bighorn Lake hydrologic unit, with a small portion in the Lower Bighorn. The Shoshone hydrologic unit provides additional surface water inputs. Bighorn Lake winds through approximately 70 miles of spectacular, sheer canyons carved by the Bighorn River. One of the outstanding characteristics of the Bighorn River is the amount of sediment it carries, especially as it nears Bighorn Lake (Soil Conservation Service 1994). With the completion of Yellowtail Dam, large amounts of the river's silt load are trapped within Bighorn Lake, and the turbidity downstream of Yellowtail is low (Soltero 1971).

The Yellowtail Dam, operated by the Bureau of Reclamation and located near the northern edge of the park, dominates BICA's hydrology and aquatic resources. Changes in the surface area of the reservoir in response to changes in lake levels are small at the north end of the park because of steep canyon walls. The opposite is true at the south end where the reservoir inundates large, shallow areas along the Bighorn and Shoshone rivers when lake levels are high and leaves these areas dry when lake levels are low (Kent 1977). Other factors that influence water levels include weather, depth of snowpack in the mountains surrounding the Bighorn Basin and Wind River Drainage, flow-rate adjustments at dams upstream from Bighorn Lake and Yellowtail Dam, and evaporation rates. The water quality of the lake is affected by upstream agricultural and industrial land use and concentrations of nutrients, sediments, and total dissolved solids generally are high.

Grand Teton National Park

Approximately 10% (31,000 acres or 48.4 mi^2) of Grand Teton National Park is covered by surface water, most of which is in six piedmont lakes along the eastern front of the Teton Range, with Jackson Lake being the largest. The Bureau of Reclamation constructed a small timber crib dam at the outlet of the natural Jackson Lake in 1906. The dam was enlarged in 1911 (after failing in 1910) and again in 1917, which raised it to full pool (25,540 acres, or 40 mi^2). About 100 alpine lakes (varying from 1 to 60 acres) are within the Teton Range, mostly above 9,000 feet elevation. Approximately 75 pothole ponds of less than 0.5 to more than 35 acres occur in the glacial drift area south and east of Jackson Lake. Two large lakes (Two Ocean and Emma Matilda) in the northeast portion of the park were not glaciated during the last advance of ice, and the origin of their basins is not known (NPS 1986).

Seven streams originating in the Teton Range drain eastward into Jackson Lake, six others drain into Cottonwood Creek and the Snake River near Moose, and three drain the southern portion of the Teton Range into Lake and Fish Creeks, which flow into the Snake River south of the park. Eight major streams drain highlands in the Bridger-Teton National Forest north and east of the park and flow into Jackson Lake or the Snake River within the park. All surface and ground water in the park drains into the Snake River, which originates in highlands of the Teton Wilderness Area, flows north and west through part of Yellowstone National Park, south through the John D. Rockefeller, Jr. Memorial Parkway and into Jackson Lake in the park. From Jackson Lake, the Snake River flows east and then south for about 25 miles before crossing the park's south boundary. Approximately 1.98 million acre feet of water (average daily flow = 2,740 cubic feet/second [cfs]) flows out of the park annually via the Snake River (NPS 2001).

Much of the eastern and central portions of the park (particularly areas covered by glacial outwash) also have extensive ground water resources (McGreevy and Gordon 1964; Cox 1974). Water tables vary from near the surface on floodplains to 30 to 60 feet below the surface on outwash flats and deeper on most upland areas. Flow is toward the Snake River, and many springs emerge along the Snake River floodplain south of the Buffalo Fork confluence. Numerous springs also emerge from limestone areas in the northwest and southwest portions of the park. Other springs are along the park's east boundary, including several thermal springs near Kelly and East Gros Ventre Butte. Another series of thermal springs are on the west side of Jackson Lake and may be associated with the Teton fault (NPS 1986).

Yellowstone National Park

Yellowstone National Park encompasses approximately 3,500-square-miles of watersheds that preserve one of the most significant, near-pristine aquatic environments in the United States, and contribute to two of the nation's farthest reaching drainages: the Missouri and Columbia Rivers. About five percent of the park is covered by water, including more than 220 lakes and 1,000 streams. Yellowstone Lake, which lies at an altitude of 7,730 feet, covers 136 square miles (87,040 acres) and is 400 feet deep, is the largest lake at high elevation in North America. As a result of both natural topography and early preservation actions, the headwaters of five major river systems (Fall, Gallatin, Madison, Snake and Yellowstone) are either in or just upstream from the park. The 670-mile Yellowstone River, the longest undammed river in the lower 48 states, plunges 308 feet at the Lower Falls in the Grand Canyon of the Yellowstone, almost twice the drop of Niagara Falls (Yellowstone National Park 1999). More than 50% of the park's surface waters are located within the Yellowstone Headwaters hydrologic unit. Other hydrologic units within park boundaries are the Madison, Snake Headwaters, Upper and Lower Henrys, North Fork Shoshone, and the Gallatin.

Park lakes and streams are free-flowing and pristine, providing high-quality recreational opportunities for public enjoyment, and supporting a diversity of aquatic life, including the largest natural cutthroat trout population in the world. This population is threatened by the presence of the non-native lake trout. Water quality is thought to be high. Natural geothermal discharges affect water temperature, pH and salinity which affect the solubility of constituents.

Therefore, the quality of water in Yellowstone National Park varies with the geologic terrain, the degree of influence from thermal water and the season. Seasonal variations in the quality of surface water occur because of runoff from snowmelt and precipitation with low dissolved-solids content and high suspended-sediment load. Conversely, base flow from ground water discharging to streams may have relatively high dissolved solids and low suspended sediment (NPS 1994).

Priority Impaired Waters

As part of the Vital Signs Program, the GRYN has been tasked with identifying and discussing the status of each water body that is quality impaired (i.e. 303[d] listed by the states) and address how each water will be monitored. A map of the GRYN 2002 303(d) waters appears in Appendix D. It is interesting to note that, in several instances water quality exceedances (as identified by Woods and Corbin 2003a, b, & c) did not support state 303(d) listings. For example, one of the reasons cited by the state for considering the Bighorn River to be impaired (e.g. formally 303[d] listed), is nitrogen (nutrient) pollution, however, none of the nitrate values from the Bighorn River at Kane exceeded the defined water quality standards (Woods and Corbin 2003a). Conversely, waterbodies with identified exceedances have not been identified by states as being impaired. In YELL and GRTE, some of these exceedances can be explained by geology and geothermal influences.

<u>Bighorn Canyon National Recreation Area</u>

The Shoshone River, from its confluence with Bighorn Lake upstream an undetermined distance appears on Wyoming's 2002 303(d) list for concerns related to fecal coliform contamination (Wyoming DEQ 2002a). Montana's 2002 303(d) list (Montana DEQ 2002a) includes the Bighorn River from Yellowtail Dam to the Crow Indian Reservation Boundary (Montana DEQ 2002b). This portion of the river is only partially supporting (refer to Appendix H for descriptions of state standards) for aquatic life and cold water fisheries due to nutrient loading. Crooked Creek also appears on Montana’s 2002 303(d) list (Montana DEQ 2002c), and is listed as only partially supporting for aquatic life and cold water fisheries due to bank erosion and habitat alterations resulting from agricultural and grazing related sources. However, in Wyoming, Crooked Creek has been classified as a 3B stream (ephemeral or intermittent tributary, not known to support fisheries or drinking water uses, and those uses are not attainable in the future). While Crooked Creek will be monitored, it will not be monitored formally as a 303(d) listed water.

<u>Grand Teton National Park</u>

No streams within park boundaries of GRTE appear on Wyoming's 2002 303(d) list as being impaired. However, the North Fork of Spread Creek, a tributary to park surface waters, currently has a watershed improvement project in place (to reduce sediment deposition) which has improved the stream's ability to support aquatic life. The stream is still considered threatened, and so is 303(d) listed by Wyoming as a waterbody with water quality threats (Wyoming DEQ 2002a & b). It is being monitored by the US Forest Service (pers. comm. Wes Smith, Hydrologist, Bridger Teton National Forest). Physical degradation of a portion of Pacific Creek (within park boundaries) was identified in Wyoming's 1998 303(d) list, but was de-listed in 2000, due to the lack of credible data to support the listing. Wyoming DEQ has scheduled monitoring of this drainage (pers. comm. Jeremy Zumberg, WY-DEQ). Synoptic studies being conducted in both of these drainages by the USGS in 2002-2003 should provide sufficient data to determine whether additional monitoring within park boundaries is needed to address water quality impairment issues.

Yellowstone National Park

Soda Butte Creek originates in Montana in an area of historical mining disturbance. As a result of these impacts, Soda Butte Creek (outside of the park's boundary) is on Montana's 2002 303(d) list (Montana DEQ 2002d), but impacts in Wyoming (inside the park's boundary) have not yet been determined (Wyoming DEQ 2002a & 2002b). At this time, Soda Butte Creek has a restoration project in place (Montana DEQ 2002e). Reese Creek is also on the Montana's 2002 303(d) list as being only partially supporting for aquatic life and cold water fisheries due to dewatering and flow alterations (Montana DEQ 2002f). Both of these creeks will be monitored as quality impaired waters.

Pristine (Outstanding Natural Resource) Waters

In addition to identifying impaired waters, the GRYN must identify and discuss waters afforded special protection status under state guidelines. The State of Wyoming has designated all surface waters located within the boundaries of Yellowstone and Grand Teton National Parks to be Class 1 waters. Class 1 waters are defined by the state as "those surface waters in which no further water quality degradation by point source discharges other than from dams will be allowed." (Wyoming DEQ 2001b). The classification of these waters corresponds with EPA's ONRW designation.

Management issues and stressors

In September 2001, park resource managers were asked to respond to a water quality monitoring questionnaire. The purpose of the questionnaire was to provide the water quality planning team with a very basic understanding of the water resources and associated management issues and stressors in each NPS unit in the GRYN (see Appendix A for a summary of this information). The following sections describe these issues in more detail, for each of the GRYN parks. Fisheries issues and concerns will not be discussed in this document, but, rather, are being addressed in GRYN's Phase II Report (Jean et al. 2003).

Bighorn Canyon NRA

Bighorn Canyon, hydrologically, is at the receiving end of an intensely industrial and agricultural basin. Potential anthropogenic sources of contamination include municipal and industrial wastewater discharges (including produced water discharges from oil and gas facilities); ranching and agricultural activities; recreational use; quarrying and mining activities; timbering operations; oil and gas exploration; and atmospheric deposition.

Various threats to BICA water resources, originating both within and outside BICA boundaries, were recently described in the park's Water Resources Management Plan (Jacobs et al. 1996). Within park boundaries, water-based recreation support facilities (in the form of campgrounds, boat ramps, parking lots and marinas) represent a threat to park water resources. Cattle grazing and herding of cattle also occurs through designated portions of the park as herds pass between private lands or from private to public grazing lands outside the park. Numerous private mineral rights for oil, gas, sand and gravel are present in the park and will remain as private property unless they are purchased or otherwise acquired by the NPS. Most of the sand and gravel are located within or near riparian areas where any surface-disturbing activities would be detrimental to water quality.

Land ownership and use patterns outside BICA are even more diverse than those within. The Crow Reservation extends on the northern end of the park. Grazing, irrigated agriculture, non-irrigated agriculture and timber production are prevalent on these reservation lands. It is expected that the Crow Water Compact, which defines the water rights of the Crow Tribe, and which was approved in the summer of 1999 by the State of Montana, will have a significant impact on the water resources of Bighorn Canyon as it develops. The BLM administers much of the land adjacent to the southern end of the park, with grazing as the predominant use. There are also inactive uranium mines, and active agate quarries adjacent to the park. U. S. Forest Service lands immediately east and west of BICA are managed for multiple uses including grazing, timber harvest and recreation. Private land holdings are extensive and are primarily concentrated in the floodplains of major rivers, and are principally used for agriculture, grazing of domestic livestock, mining and residences.

Both the Shoshone and Bighorn Rivers have been greatly altered by several large irrigation, power, and flood control projects (Akashi 1988). In spite of the fact that many small, low-order streams are still unaffected by diversions and reservoirs, natural snowmelt hydrographs of the Shoshone and Bighorn Rivers longer exist within the park, affecting all aspects of bank stability, channel substrate, and riparian vegetation. The Shoshone River is one of the main contributors of suspended sediments to the Bighorn River, and the major sources of sediments in the Shoshone are erosion from irrigated croplands, rangelands, and streambanks (Soil Conservation Service 1994). Water temperature of the Bighorn River is influenced by residency in the lake. The water quality and riparian conditions along major tributaries such as the Bighorn and Shoshone Rivers and Crooked Creek are considered to be threatened. Tributary streambeds are altered, side canyons experience slumping, and noxious weeds invade wetland and riparian areas. Historic cottonwood stands are decadent. There are major infestations of Russian olive, salt cedar, knapweeds and Halogeton (saltlover) in large portions of the park. All of this has contributed to a loss of functional attributes of riparian areas at the southern end of the park and below Yellowtail Dam. Impairment of water quality and declining aquatic and riparian conditions have been documented along Trail Creek and Layout Creek due to historic and current livestock and wild ungulate grazing activity.

Siltation and sedimentation in upper portions of Bighorn Lake, especially around Horseshoe Bend, are serious problems. It is expected that this deposition of silt ultimately will result in the loss of the marina and swimming areas at Horseshoe Bend (Jacobs et al. 1996). The trophic status of the lake is also of great concern, and has been the subject of several studies. Trophic conditions change progressively from the upper (southern) to the lower (northern) portion of the lake, and the upper pool experiences eutrophic conditions (Jacobs et al. 1996). Contamination from pesticides, nutrients, salts and fecal coliform bacteria may play a large role in deteriorating water quality within the lake. There are concerns that native macrobenthic and fish species are being lost.

Grand Teton NP

Water quality throughout Grand Teton National Park is generally considered excellent (Woods and Corbin 2003b). Major threats to water resources, as identified by park staff, are summarized in Appendix A. Threats to water resources were also extensively discussed in the Grand Teton National Park Water Resources Scoping Report (Mott 1998).

Jackson Lake dam changed the streamflow regime, bedload transport processes and channel dynamics within the Snake River. Issues associated with the dam include: fluctuating shoreline elevations in Jackson Lake; maintenance of instream base flows; attenuation of peak flows; and altered riparian community structure and function. Researchers studying riparian vegetative communities noted that changes could not be explained by hydrologic modifications alone (Mott 1998). Grazing by cattle, elk, antelope, and wild ungulates affect deciduous woody vegetation. Cattle, horse and wild ungulate access to small streams can also elevate sediment, bacterial and nutrient loads in these streams and reduce stream bank strength due to trampling and intense grazing levels.

The construction of facilities such as the park headquarters, bridges, streamside campgrounds, boat accesses and irrigation headgates have required efforts to increase the stability of some stream reaches. Flood control levees were constructed along the lower reaches of the Snake River and along Pilgrim Creek within Grand Teton National Park. These levees have resulted in the lowering of channel bed elevations, the destruction of vegetated islands and the elimination of trout spawning habitat. The armoring of bridges interferes with natural stream functions and degrades physical habitats and aesthetic values.

Recreational activities such as camping, hiking, floating, snowmobiling and horseback riding can result in detectable water quality degradation in heavily used areas (Mott 1998). Additionally, some visitor facilities produce seasonally large volumes of wastewater. Major treatment plants exist at Colter Bay, Signal Mountain, Flagg Ranch and Moose. Effluents near Flagg Ranch and Moose probably discharge into the Snake River (Mott 1998).

Issues related to water rights and irrigation arise from both local and regional water allocations. Locally, water is withdrawn from the Snake River and its tributaries to provide irrigation needs both internal and external to the park, and commercial and residential withdrawals. Regionally, water stored behind Jackson Lake Dam supports irrigated agricultural lands, mostly in Idaho. Removal of water from park streams changes their base flow characteristics, altering natural stream dynamics and degrading stream habitat.

GRTE has many miles of paved and unpaved roads. A report by the Federal Highway Administration (1986) concluded that there is an abundance of gravel within the park that could potentially be used for road building and maintenance. There are 38 borrow pits in the park, ranging in size from 0.1 to 40 acres, from which at least 100 cubic yards of materials have been excavated (NPS 1986). In addition to upland sources, nearly every accessible stream has been targeted for gravel mining operations (NPS 1988).

Adjacent Forest Service lands are subject to oil and gas development. Given the extensive carbonate strata, the karst hydrology, and the documented interbasin transfer of groundwater (Huntoon and Mills 1987), there is the possibility that contaminants generated by well drilling and oil and gas production could be carried through the karst ground water network to park tributaries.

Atmospheric deposition sources must be considered as threats to the "Outstanding Natural Resource Waters" in both GRTE and YELL. Snowpack and wet deposition data collected in the GYA illustrate the importance of identifying the nitrogen sources of air pollutants (NPS-ARD 2002; Turk et al. 2001; Ingersoll et al. 1997). The potential for additional sulfur deposition is present due to the possible increase in coal burning in the western U.S. Local sources of air pollution, such as snowmobile exhaust, can result in greater loadings of organics, nitrogen and sulfur species to snowpacks (Ingersoll 1999), and snowpack surveys conducted annually since 1993 have shown consistent "hotspots" of inorganic nitrogen deposition downwind of agricultural and industrial (INEEL, and fertilizer plants) in Idaho (Turk et al. 2001; Clow et al. 2002). The future may well bring accelerated energy development in Montana and Wyoming, with plans for extensive development of coalbed methane wells and the possibility of new electrical generating plants (e.g. Roundup plant in Montana). Southern Idaho has shown an increase in confined animal feeding operations (CAFOs), resulting in the uncontrolled emissions of ammonia. There is international concern about the possibility of exponential growth in inorganic nitrogen emissions from industrial, vehicular and agricultural sources worldwide (Cowling et al. 2002). Melting of contaminated snowpacks can result in changes to soil processes and alterations in surface water chemistry, which can, in turn, affect aquatic biota in high elevation lakes and streams. There are also concerns for atmospheric deposition of toxic elements, especially mercury and pesticides.

Yellowstone NP

Although the park's water quality resources as a whole are believed to be in excellent condition, both internal and external human activities affect water quality and the wildlife that depends on it (Yellowstone National Park 1999). In the Soda Butte drainage near the park's northeastern corner, leaching from historic mines still pollutes the water. An estimated 150,000 cubic yards of mine waste containing arsenic, copper, iron, lead, and zinc are stored on the valley floor just outside the park's northeast entrance. In 1950, an impoundment failure washed toxic material more than 15 miles downstream into the park. Reduced invertebrate populations and elevated levels of copper in fish tissue are still in evidence 50 years later. Water rights in this drainage are claimed by upstream users. The potential also exists for depletion of the park's groundwater resources as a result of oil and gas or geothermal drilling outside park boundaries.

Internal threats include accidental spills from sewage treatment plants (YELL has 26 wastewater treatment systems including septic tanks, trickling filters, aerated lagoons and activated sludge systems that handle 270 million gallons annually through 250,000 feet of buried pipe); the leaking of underground petroleum storage tanks; spills of petroleum products along roadways; sedimentation from erosion of social trails, stock use, and construction projects; storm water runoff from developed areas; pollution from boats; pollution from backcountry toilets near lakeshores; leaching from abandoned dumps; pollution from pesticide use; and snowpack deposition from snowmobile emissions (Yellowstone National Park 1999).

Whirling disease was found in Yellowstone Lake in 1998. Recently introduced New Zealand mud snails, which have been found to occur in both YELL and GRTE, may directly affect aquatic invertebrates, and pose additional threats to already imperiled cutthroat populations.

Historic and current monitoring efforts

A map of current and historic monitoring locations in the GRYN appears in Appendix E. For the most part, these locations were identified in the Baseline Water Quality Data Inventory and Analysis Reports, jointly produced by the Servicewide Inventory and Monitoring Program and the Water Resources Division (National Park Service 1994, 1998b, 2001). These reports provided the results of surface-water-quality data retrievals from six of the USEPA's national databases:

1. STORET;
2. River Reach File (RF3);
3. Industrial Facilities Discharge (IFD);
4. Drinking Water Supplies (DRINKS);
5. Water Gages (GAGES);
6. Water Impoundments (DAMS).

In addition, these reports provide:

- a complete inventory of all retrieved water quality parameter data, water quality stations, and the entities responsible for the data collection;
- descriptive statistics and appropriate graphical plots of water quality data characterizing period of record, annual, and seasonal central tendencies and trends;
- a comparison of the park's water quality data to relevant EPA and WRD water quality screening criteria; and
- an Inventory Data Evaluation and Analysis (IDEA) to determine what Servicewide Inventory and Monitoring Program "Level I" water quality parameters (NPS 1993) have been measured within the study area.

The report for Yellowstone was completed in 1994, Bighorn Canyon's in 1998, and Grand Teton's in 2001. The information contained in these reports was updated and reviewed as part of a task agreement with the University of Montana in 2002 (Woods and Corbin 2003a, b, c).

<u>Bighorn Canyon NRA</u>

In 1996, a Water Resources Management Plan for BICA was published (Jacobs et al.), providing direction for future water related research. In 1998, the NPS Water Resources Division provided BICA with a document summarizing relevant surface water quality data as retrieved from six EPA national databases (National Park Service 1998b). The following represents a summary of the monitoring efforts at BICA:

- Streamflow has been measured on the Bighorn River since 1928, and on the Shoshone River from 1967 through 1993(USGS 2003).
- Aquatic biota have been measured periodically, with most of the measurements being conducted immediately after impoundment of the Bighorn River (Swedeberg 1970-78, Fredenberg 1985, Redder et al. 1986). The Wyoming Department of Environmental Quality collected macro-invertebrate samples from Crooked Creek and the Shoshone

River within BICA boundaries during the summer of 2001, however, results are not yet available. Additional aquatic macro-invertebrate sampling was conducted by YELL staff at a limited number of sites during fall 2002.

- The water chemistry (anions, cations, nutrients, turbidity, trace metals, pH, temperature and conductivity) of the Bighorn River and Bighorn Lake from 1968-1970 was documented by Soltero (1971) and Wright and Soltero (1973). Water temperature, pH, dissolved oxygen, specific conductivity, nutrients, suspended sediment and fecal coliforms have been monitored quarterly since 1998 by the USGS on the Bighorn River at Kane and on the Shoshone River near Lovell, as part of a collaboration with the WY-DEQ.
- Bed sediments and fish tissue analyses were conducted in 1998 as part of the USGS NAWQA program on the Bighorn and Shoshone Rivers.
- Fish tissue analyses, habitat, aquatic community and water chemistry data were collected in 2002 as part of the EPA's EMAP program.
- Several post-impoundment studies (Soltero 1971, Soltero et al. 1973, Kent 1977, US-EPA 1977, Horpestad 1977, Lee and Jones 1981) reported on the trophic status, temperature ranges and clarity of Bighorn Lake. Limited studies have been conducted to detect concentrations of PCBs and concentrations and sources of some heavy metals (Phillips et al. 1987, Phillips and Bahls 1994). Also the rates and patterns of sedimentation have been studied and reported on (Lee and Jones 1981, Blanton 1986, Soil Conservation Service 1994, Martin 1995).
- The Bureau of Reclamation continuously monitors Bighorn Lake water levels.
- Riparian vegetation dynamics along the Bighorn River were described by Akashi in her 1988 M.S. thesis.
- Groundwater and water use and quality characteristics were described in a U.S. Geological Survey Water Investigations Report (Plafcan et al. 1993).
- Segments of the Bighorn and Shoshone Rivers within BICA boundaries and Bighorn Lake are regularly monitored by park staff , from May through October of each year, for fecal coliform levels so as to assure compliance with EPA and Wyoming Department of Environmental Quality full-body contact recreation water quality standards. This monitoring began in late 1990, and was done by maintenance personnel as part of a comprehensive plan developed by Don Fernau, BICA employee (personal communication, Don Fernau). This monitoring responsibility was turned over to the Ranger Division in 2001. No monitoring for fecal coliforms has been accomplished from 2001-2003, due to low lake water levels.

<u>Grand Teton NP</u>

In 1998, a Water Resources Scoping Report for GRTE was published (Mott), providing direction for future water related research. In 2001, the NPS Water Resources Division provided GRTE with a document summarizing relevant surface water quality data as retrieved from six EPA national databases (NPS 2001). The following represents a summary of the monitoring efforts at GRTE:

- Stream flow is measured by the USGS at four stations within the park: the Snake River at Flagg Ranch (1990-present), the Snake River below the Jackson Lake Dam, the Snake River at Moose (1995-present), Pacific Creek, and Buffalo Fork. Stream flow data are reported by the U.S. Geological Survey in annual reports of regional water resources data.

- Testing for fecal coliform, including DNA source tracking of *E-coli*, began in 1996 in selected backcountry streams, and has continued to date.
- The trophic state of select alpine and low elevation lakes was documented between 1995 and 1997 (Miller et al. 1996). The project found that most of the high-elevation lakes were determined to be oligotrophic to slightly mesotrophic and other low-elevation lakes, such as Cygnet Pond, Swan Lake, and Two Ocean Lake, to be eutrophic.
- The Bureau of Reclamation continuously monitors Jackson Lake water levels.
- Approximately 23 wells adjacent to sewage ponds and leach fields within park boundaries are presently being monitored once a year (presently under agreement with the USGS), for basic water quality parameters, fecals, and nutrients, to comply with WY-DEQ regulations. Additionally, Snake River Pit ground water levels are monitored on a biweekly basis from wells installed by the USGS in 1997.
- The first monitoring site for the National Water Quality Assessment (NAWQA) program was established in the Snake River - Flagg Ranch area in the early 1990's. A second site was established at Moose in 1996. Parameters measured quarterly include water temperature, pH, dissolved oxygen, specific conductivity, nutrients, and suspended sediment. The Moose site includes a real-time, continuous monitor for temperature, pH, dissolved oxygen and specific conductivity.
- Funding was obtained in 2001 to conduct a synoptic survey of baseline water-quality parameters in five major tributaries of the Snake River. This study collected data on all of the parameters mentioned above, as well as pesticides and trace metals.
- Snow pack data has been collected in Jackson Hole since the early 1900's, typically to forecast runoff and potential irrigation water supplies. Currently, the snow pack distribution in and around GRTE is being studied because of its relationships to animal movement, the location of winter ranges, and the availability of forage. Correlations between snow pack and soil moisture, forage production, plant phenology, and other plant/soil moisture and animal responses are also considered. The snow pack distribution study in GRTE is a NPS driven project, that is being carried out through a cooperative agreement between NPS, the Natural Resource Conservation Service (NRCS, previously the Soil Conservation Service), Montana State University (MSU), and Colorado State University (CSU). The objective of the study is to process historic data and produce GIS-based model on snow pack distribution across the Snake River Drainage above Jackson, including the lower elevations of GRTE, the National Elk Refuge, and the Gros Ventre watershed.

<u>Yellowstone NP</u>

Yellowstone National Park has neither a water resources scoping report nor a water resources management plan to guide their water quality monitoring efforts. However, YELL has an active water quality monitoring program. Groundwater, surface waters and geothermal resources are monitored. The following represents a summary of the water quality monitoring efforts at YELL:

- In 2002, a pilot program to monitor water quality was initiated. To accommodate spatial and temporal variability among the many water quality parameters, such as chloride flux, seventeen fixed sites (twelve of these stations are located on major waterways with ten near USGS gage stations) were located throughout YNP with a sampling frequency established at two-week intervals, allowing for the detection of large-scale habitat changes and biotic responses between years (Soballe and Fischer 2001).

- Five fixed-site stations were established at historic Yellowstone Lake water quality sampling stations (Koel et al. 2002), with sampling taking place between May and October (during ice-free periods). Additional sampling sites were added in 2003 in the two southern arms of Yellowstone Lake.
- Yellowstone also participates in the USGS National Water Quality Assessment (NAWQA) program, and has monitoring stations at Soda Butte Creek at the park boundary, Blacktail Deer Creek, and on the Yellowstone River near Yellowstone Lake Outlet.
- The NPS, USGS and others have conducted pollution studies on Soda Butte Creek (a GRYN 303[d] listed stream) since the 1960s.
- The USGS maintains gaging stations at various locations within and near YELL including: Madison River, Firehole River, Gibbon River, Gallatin River, Yellowstone River at Yellowstone Lake outlet, Soda Butte Creek (2 locations), Gardner River, Boiling River, and Yellowstone River at Corwin Springs. More than a dozen additional stations have been operated by the USGS at various times within park boundaries.
- Four rivers draining YELL (the Fall, Madison, Snake, and Yellowstone Rivers) have been monitored for chloride flux, a surrogate for heat flow measurements, from 1983 through the present, with the exception of 1995 and 1996 (Norton and Friedman 1985, Norton and Friedman 1991).
- To monitor fish, streamflow and allocated withdrawals in Reese Creek (a GRYN 303[d] listed stream), which is compromised by historical irrigation practices and flows along Yellowstone's northern boundary, a Parshall flume and gages were installed in 1984. Several representative fishery stream types were surveyed by Muttkowski (1929), and more systematic stream inventories began in the 1960s. By 1990, more than 600 streams had been inventoried (Jones et al. 1990).
- Backcountry lake surveys were conducted from 1963-1986 (Jones et al. 1986); 112 lakes were surveyed for physical, chemical, and biological parameters. Although no similar surveys have been completed since 1987, NPS staff plans to re-initiate this program (Koel et al. 2002).
- Four lakes located in YELL were part of chemistry/precipitation study (Clow et. al. 1999).

Monitoring Water Quality on Adjacent Lands

At the GRYN water quality planning workshop held in Gardiner, MT, in June 2002, neighboring agencies were invited to share their water quality monitoring strategies and protocols so that planned GRYN water quality monitoring efforts may both enhance and gain insight from other regional efforts. The USGS described its local NAWQA, high elevation lakes monitoring, and ecosystem monitoring efforts. The EPA and the WY-DEQ presented their Environmental Monitoring and Assessment Program (EMAP) and Beneficial Use Reconnaissance Program (BURP), respectively. The USFS discussed their Inland West Watershed Initiative and compliance monitoring. Maps showing locations of USGS NAWQA monitoring stations and EMAP monitoring sites are included in Appendix F, along with a table of monitoring locations and parameters.

B. Problem Statement/Values to be Protected

Bighorn Canyon NRA

In Bighorn Canyon, most of the surface waters suffer from some type of impairment. The value to be protected/desired future condition would be (at best) to improve the water quality, and (at least) to prevent any further degradation. The parameters that define the current and desired future conditions will be defined as quantitatively as possible based on existing information and proposed synoptic studies. Park resource managers at BICA identified waterbodies critical to the purpose of the park (Appendix A). These included Bighorn Lake, the ponds on Yellowtail Habitat, Trail Creek, Layout Creek and the springs in Dryhead. All of these waterbodies are perceived by park managers as either impaired or threatened.

Grand Teton NP

Because all of the waters in GRTE have been classified as ONRWs, the value to be protected/desired future condition is to preserve pristine (un-impacted) condition status. In this case, the goal is typically to prevent degradation. The final water quality monitoring plan will define the desired future conditions, including variability ranges during various regional climatic and flow conditions, as quantitatively as possible, based on the results of current and future synoptic studies.

Resource managers at GRTE identified waterbodies critical to the purpose of the park (Appendix A). These included Jackson Lake, the Snake River, western Snake River tributaries (backcountry creeks), eastern Snake River tributaries, and high alpine lakes. All of these waters are perceived by park managers to be potentially threatened in the long term.

Yellowstone NP

Similarly, in YELL, all waters have been classified as ONRWs, and so the value to be protected/desired future condition is to preserve pristine (un-impacted) condition status. Park resource managers identified waterbodies critical to the purpose of the park (Appendix A). These included Yellowstone, Heart and Lewis Lakes; Yellowstone River above the falls; Madison, Firehole, Gibbon, Lamar, Gallatin, Snake, Bechler and Gardner Rivers and Soda Butte Creek. All of these waterbodies, with the exception of the Yellowstone River above the falls which is considered to be pristine, are perceived to be impaired in the park's perspective, and all are potentially threatened in the long and/or short term.

C. Questions to be Answered/Objectives

The following mission statement for water quality monitoring was developed at a GRYN meeting in June of 2001:

> “The Greater Yellowstone Network, through the Vital Signs Monitoring Program, seeks to prevent water quality degradation and to preserve unimpaired water quality of all surface water resources.”

In support of this mission, the Greater Yellowstone Network further proposed to describe the ecological condition (health) of the selected park aquatic resources (including rivers, streams, lakes, pond, estuaries, and riparian and wetland resources) by: 1) establishing the baseline physical, chemical and biological conditions of these resources; 2) identifying key species, habitats and/or processes as indicators of resource conditions; 3) identifying specific areas which are vulnerable to degradation from activities both within and external to the park; and 4) establishing an integrated monitoring program, based on 1-3 above, that will provide scientifically sound information for managing park water resources.

Following the development of its mission statement, the GRYN adopted the general monitoring goals (NPS 2003b, wqPartA) recommended by the NPS-WRD):
Monitor quality impaired waters to enable the GRYN to:

- determine whether the overall goal of improved water quality is being achieved; and
- gather information on the pollutants that exceed standards to assist the park and the state in designing specific pollution prevention or remediation programs through Total Maximum Daily Loads

At an early water quality workshop (December 2001) the following "questions to be answered" were suggested for use by the GRYN:

How does a change in precipitation regime affect the hydrologic cycles?
How do things (land use, precipitation patterns, airborn deposition) change over time?
What is the range of (natural) variation for specific water quality parameters?
How do both wild and prescribed fires affect/change water quality?
How do current wildlife management practices affect water quality?
Are pH, nitrogen and alkalinity changing over time?
What are the effects of herbicide use (within the parks) on water quality?

Several approaches for developing water quality monitoring goals and objectives were discussed at the Missoula workshop held in June of 2002, including those used by the USGS-NAWQA and EPA-EMAP programs.

The NAWQA program was designed to answer 3 questions:

1. What are the current water-quality conditions for a large part of the nation's freshwater streams and aquifers? (status)
2. How is water quality changing over time? (trends)
3. What are the primary natural and human factors that affect water quality? (understanding)

EMAP objectives include:

1. Estimate status and trends on a regional basis with known confidence;
2. Estimate geographic coverage;
3. Seek associations between indicators and stressors;
4. Provide tools to allow assessments.

To assist in the integration of specific monitoring objectives into park programs (a primary goal of the GRYN program is that the GRYN Vital Signs Monitoring Program becomes intimately integrated into park programs), each member of the WQWG was asked to develop a table (Appendix G) that:

1) lists each waterbody in the park that they think should be monitored;

2) identifies which of the vital signs (invertebrates, discharge, specific anions/cations) should be monitored on those waterbodies;
3) provides some idea of how they should be monitored (continuous monitoring, high/low flow, quarterly, biweekly during the summer, etc.); and
4) provides some indication of why we are monitoring this waterbody, from a vital signs perspective (i.e., are we monitoring this waterbody because it is important for monitoring ecosystem health, understanding park-specific issues, or is it relevant to management actions, or all of the above?).

For the purposes of this report, the GRYN has grouped its water quality monitoring objectives into three categories: impaired (303[d] listed) waters; other waters important to the significance of the park; and pristine waters. For impaired waters, the specific monitoring objectives are based on state water quality standards.

Monitoring Objectives for Impaired (303[d]) Waters

<u>Background</u>
Several streams/waterbodies in the GRYN require monitoring for regulatory purposes. Monitoring strategies must be designed not just to determine if water quality standards are being exceeded, but to detect improvements (or lack there of) in water quality related to the listed reason for impairment. Monitoring of quality impaired waters also requires adherance to state recommended guidelines and protocols. Regulations regarding 303(d) listing vary from state to state. In part, the parameters to be monitored for regulatory purposes are dependent upon the specific criteria that each state uses to define the use categories or classes of its surface waters, and may or may not correspond to GRYN selected Vital Signs. A discussion of these standards can be found in Appendix H. In addition, temperature, pH, DO, specific conductivity and some measure of flow or discharge have been designated as "core parameters" by NPS-WRD, and must be monitored in conjunction with 303(d) listed parameters of concern at all locations.

Questions to be answered.
The general goals guiding the monitoring of impaired waters were combined with information related to the state specific standards (Appendix H) to help articulate more detailed (regulatory) questions to be answered as follows:

<u>Shoshone River</u>
The Shoshone River, from its confluence with Bighorn Lake upstream an undetermined distance, has been classified by the State as 2AB. Class 2AB waters are those known to support game fish populations or spawning and nursery areas at least seasonally. These waters are presumed to have sufficient water quality and quantity to support drinking water. Class 2AB waters are also protected for nongame fisheries, fish consumption, aquatic life other than fish, primary contact recreation, wildlife, industry, agriculture and scenic value uses.

Based on monitoring conducted by the state in 2000 and 2001, this portion of the Shoshone River had exceedences of the fecal coliform standard and is impaired for contact recreation

(Wyomng DEQ 2002a & b). There is an existing water quality station on the Shoshone at Kane, maintained by the USGS, which is located within the portion of the Shoshone that is on the state 303(d) list. This location could be appropriate for monitoring fecal coliform levels to address regulatory issues, however, it is located outside park boundaries. A monitoring station could be located within park borders at the confluence of the Shoshone River and Bighorn Lake.

Based on Wyoming standards for fecal coliforms (see Appendix H), the regulatory question(s) to be answered for the Shoshone River are framed as follows:

1a) Do fecal coliform concentrations, at the confluence of the Shoshone River and Bighorn Lake, exceed a geometric mean of 200 organisms per 100 milliliters (based on a minimum of not less than 5 samples obtained during separate 24 hour periods for any 30 day period)?

1b) Do fecal coliform concentrations, at the confluence of the Shoshone River and Bighorn Lake, exceed the geometric mean of 400 organisms per 100 milliliters (based on 3 separate samples collected within a 24 hour period)?

<u>Bighorn River</u>

The 6.9 mile segment of the Bighorn River, from Yellowtail Dam to the Crow Indian Reservation boundary has been classified by the state of Montana as B1. Waters classified B-1 are to be maintained suitable for drinking, culinary and food processing purposes, after conventional treatment; bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply. It appears on the State's 2002 303(d) list as being only partially supporting for aquatic life and cold water fishery. Nitrogen due to "other" sources is listed as the cause. Data contributing to this listing were limited, based mostly on studies regarding gas bubble trauma conducted in the early 1980's (Montana DEQ 2002b). Evaluation of two or more biological assemblages were used in the assessment. There is an existing USGS gaging station (USGS06287000), Bighorn River near St. Xavier, located within this reach.

Based on Montana's standards for nitrogen and the required documentation for "partially supporting" waters, the regulatory questions to be answered for the Bighorn River might be as follows:

2a) Does the geometric mean of nitrogen concentrations as (N) at the Bighorn River near St. Xavier exceed 10,000 μg/l?

2b) What is the natural range of variability of nitrogen concentrations as (N) in the Bighorn River near Xavier?

2c) Does the MT impairment score (based on Taxa Richness, EPT Richness, Biotic Index, % Dominant Taxon, % Collectors, % EPT, Shannon Diversity, % Scrapers+Shredders, #Predator Taxa and % Multivoltine) range between 0.75-1.00 (fully supporting) in the Bighorn River near Xavier?

Soda Butte Creek

The 4.2-mile segment of Soda Butte Creek from the McLaren tailings to the Yellowstone National Park boundary was assessed by Montana DEQ in April 1999. This segment was classified as B1, and only partially supporting for aquatic life and cold water fisheries due to metals contamination from the McLaren mine tailings. These findings were based on fixed station physical/chemical sampling (conventional plus toxic pollutants) and benthic macroinvertebrate surveys. A number of macroinvertebrate samples were collected in this reach. Analysis of existing data by MT-DEQ indicated that most of these samples show impacts due to metals contamination from the McLaren tailings, as well as some indication of nutrient enrichment from Cooke City. Chemical data show significantly elevated levels of metals in some parts of the stream due to the McLaren Tailings (Montana DEQ 2002d). A USGS gaging station (USGS06187950), on Soda Butte Creek near Lamar Ranger Station, could be utilized for monitoring purposes. A second USGS station, Soda Butte Creek at Silver Gate, located at the park boundary, was sampled during 2000-2001 as part of the USGS NAWQA program. These data could be used to help establish baseline information.

For Soda Butte Creek, the regulatory questions to be answered might be:

3a) Does the MT impairment score (based on Taxa Richness, EPT Richness, Biotic Index, % Dominant Taxon, % Collectors, % EPT, Shannon Diversity, % Scrapers+Shredders, #Predator Taxa and % Multivoltine) range between 0.75-1.00 (fully supporting) at Soda Butte Creek at Silver Gate?

3b) Does the geometric mean of nitrogen concentrations as (N) at Soda Butte Creek at Silver Gate exceed 10,000 μg/l?

Montana DEQ recognized metals contamination from the McLaren tailings as a source of impariment for Soda Butte Creek. Fish tissue analysis for metals, when performed multiple times over a several year period can provide a time-integrated measure of stream meatls contamination (personal comunication, Robert Swanson, USGS). Also, the results of a synoptic study being conducted in 2003 (and funded by the the GRYN) are expected to provide additional guidance related to appropriate monitoring protocols. Therefore, additional "questions to be answered" for Soda Butte Creek may be framed as follows:

3c) What are the levels of metal contamination in fish tissue at Soda Butte Creek at Silver Gate?

3d) Are concentrations of metals in fish tissue at Soda Butte Creek at Silver Gate decreasing?

Reese Creek

The 5.2 mile segment of Reese Creek from the state border to the mouth was assessed by Montana DEQ in March 1999. The stream is classified as B1, based on existing biological data (benthic macro invertebrate surveys, fish surveys) and a visual based habitat assessment. According to USFWS (Mahoney 1987) this stream is heavily dewatered in its lower reaches during the period in which Yellowstone cutthroat trout are typically making spawning migration runs. Ranges of core parameters are stated as: pH, 6.8-7.8; specific conductivity, 155-275; temperature, 7ºC-17ºC (Montana DEQ 2002f). There are no USGS gage locations on Reese Creek in Yellowstone National Park. However, to monitor fish, streamflow and allocated withdrawals in Reese Creek, a Parshall flume and gages were installed on Reese Creek in 1984 by YELL fisheries staff. Potential sampling locations could be Reese Creek at the state boundary or Reese Creek at the park boundary, or both.

The regulatory questions to be answered for Reese Creek might be:

4a) Does the MT impairment score (based on Taxa Richness, EPT Richness, Biotic Index, % Dominant Taxon, % Collectors, % EPT, Shannon Diversity, % Scrapers+Shredders, #Predator Taxa and % Multivoltine) range between 0.75-1.00 (fully supporting) at several locations along the length of Reese Creek from the state boundary to the northern boundary of Yellowstone National Park?

4b) What fish assemblages are present at several locations along the length of Reese Creek from the state boundary to the northern boundary of Yellowstone National Park?

The GRYN is undertaking an extensive process (in Phase III) to develop monitoring objectives, followed by sampling design and sampling protocols. This process will be used to develop the monitoring objectives for the selected vital signs, including those related to water quality.

Monitoring Objectives for Other Waters Important to the Purpose of the Parks

<u>Background</u>
BICA is unique in the GRYN in the sense that it is the only member park not containing any waters classified as pristine, such as ONRWs. Although several BICA waters will be monitored for regulatory purposes, the GRYN WQWG felt it was important to review additional water quality monitoring needs of Bighorn Canyon. The water resources of BICA are significant, but there have been few long-term studies documenting water quality. In addition, as previously mentioned, BICA is at the receiving end of an intensely industrial and agricultural basin. In Bighorn Canyon, monitoring objectives will have an emphasis on impairment issues and baseline sampling.

Monitoring Objectives for Pristine Waters (ONRWs)

<u>Background</u>
All of the waters in Grand Teton National Park and Yellowstone National Park have been classified by the states as Outstanding Natural Resource Waters. The GRYN has adopted the following nationwide goals for monitoring these waters:
Monitor ONRWs and other pristine waters to:

- allow characterization of existing water quality and to identify changes or trends in water quality over time, and
- allow identification of specific existing or emerging water quality problems

The parameters monitored for the GRYN's Outstanding Natural Resource Waters will correspond to the water quality related Vital Signs selected for the GRYN.

III. Conceptual Models

Conceptual models have been developed for the GRYN, and can be reviewed on the GRYN's website (GRYN 2003). Vital signs to be monitored should be conceptually relevant to the assessment question and to the ecological resource or function at risk. Changes in variables or metrics should either directly or indirectly correspond with changes in the status of the resources being protected. Conceptual models help illustrate the relationship of selected Vital Signs (described in Section IV, below) to the ecosystems being monitored (Table 2). Several of these models relate directly to water quality. Dr. Robert Hall (University of Wyoming), designed both the hierarchical box-and-arrow and the narrative conceptual models for GRYN lakes and rivers. Dr. Duncan Patten (Big Sky Institute) developed the GRYN models for riparian and riverine ecosystems.

These conceptual models (Appendix I and J) consist of Drivers, Stressors, Biological Effects, Indicators and Measurements. Vital Signs can emerge from any level in the models. Model levels were defined in GRYN's Phase 2 Report (Jean et al. 2003) as follows:

Drivers are major forces of change such as climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events (e.g., droughts, floods, lightening-caused fires) that have large-scale influences on the attributes of natural systems. Drivers can be natural forces or anthropogenic. Drivers operate on national or regional levels.

Stressors are physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include air pollution, water pollution, water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, and land-use change. They act together with drivers on ecosystem attributes. Stressors operate on more localized levels than drivers.

Ecological effects are the physical, chemical, biological, or functional responses of ecosystem attributes to drivers and stressors.

Indicators are an information-rich subset of attributes with respect to providing insight into the quality, health, or integrity of the larger ecological system to which they belong (Noon 2002). **Vital Signs** describe all the elements, processes, and indices actually measured or evaluated. Thus, all indicators selected for evaluation are Vital Signs, but all Vital Signs may not be indicators.

Measurements are the specific variables used to quantify the condition or state of an attribute or indicator. These are specified in definitive sampling protocols. For example, stream acidity may be the indicator, while pH units are the measure.

Table 2. Relationship of selected vital signs to conceptual models.

Vital Sign	Model	Level (name)	Proposed Measurement
Streamflow	River Model	Stressor (hydrology);	discharge
	Riparian Model	Stressor (altered hydrograph)	
	Riparian Model	Stressor (flow magnitude)	
Water chemistry	River Model	Stressor (solute concentrations, nutrient concentrations)	Major anions and cations; trace elements; nutrient concentrations;
	Lake Model	Stressor (solute concentrations, nutrient input)	
River invertebrate assemblages	River Model	Indicator (invertebrate populations);	Biotic indices; O/E ratios;
	Lake Model	Measure (invertebrate population estimates)	
	Riparian Model	Measure (aquatic biota)	
Algal species composition and biomass	Lake Model	Indicator (algae/ macrophyte biomass;	Water clarity (secchi); chlorophyll concentration; Biomass;
	River Model	Indicator (algae/ macrophyte biomass;	Biomass;
E. coli	River, Lake, Riparian	Not specified in existing models, but could be considered to be an indicator of 'Human Impacts and Activities' (Driver)	Number of colonies per 100 ml water
Groundwater quantity and quality	River Model	Biological Effect (groundwater flow)	Groundwater levels and flowpaths;
Reservoir elevation	Lake Model	Stressor (water level)	Lake water levels
Continuous water temperature	Lake Model	Stressor (temperature)	Water temperature in degrees Celsius
	River Model	Stressor (temperature regime)	
Stream sediment transport	River Model	Stressor (sediment input)	?
	Riparian Model	Biological Effect (fluvial/geomorphic dynamics)	
	Riparian Model	Biological Effect (riparian vegetation dynamics)	
Watershed budgets	Lake Model	Biological Effect (nutrient dynamics)	?
	River Model	Biological Effect (nutrient dynamics)	

IV. Vital Signs

A. What Will Be Measured?

The GRYN has undertaken an extensive process to create a defensible list of vital signs. This process began with the Delphi scoping survey, where 100 subject experts from inside and outside the parks nominated potential candidate vital signs in an on-line internet survey. In March 2003, two workshops were held with park staff and managers to critique and provide input to the vital signs nominated and to discuss the desirable characteristics of a vital sign – selection criteria – that would later be used to prioritize the nominated candidate vital signs. In May 2003, during the GRYN Vital Signs Monitoring Workshop, dozens of subject-area experts were invited to apply the selection criteria using a decision support process that emphasized the desirable characteristics of a vital sign, to rank the proposed candidate vital signs. This workshop resulted in a ranked list of 121 candidate vital signs.

From the list of 121, the GRYN program manager chose the highest scored candidate vital signs—those ranking 0.9 and above (out of 1.0)—reducing the list to 40 candidate vital signs, and presented them to the GRYN Technical Committee (TC) in July 2003. TC members were allowed to add other candidate vital signs that scored below 0.9, with the condition that the vital signs seemed important for monitoring ecosystem health, understanding park-specific issues or were particularly relevant to management actions. This exercise resulted in a list of 64 candidate vital signs for detailed discussion.

Considering the list of 64, the TC members were asked to evaluate each vital sign individually and decide the following: (1) if the vital sign is currently being monitored, should continue to be monitored and if the data is readily available at little or not cost to the GRYN; (2) if the vital sign is not currently being monitored, is it important and should remain on the selected list; or (3) if the vital sign could be integrated with another vital sign e.g. terrestrial vegetation communities. If none of these applied, the vital sign was dropped from the list. This process resulted in the selection of 44 vital signs. The list was approved one month later by the Board of Directors.[1]

A table of the 44 selected vital signs may be found in Appendix K. From this list of 44, the GRYN program manager identified ten, related to water quality, to be included in this report. The ten water quality related vital signs (and associated parameters) that emerged from the GRYN selection process are described further on in this section.

In addition to the selected vital signs, NPS-WRD has designated a suite of "core parameters". This core data set is intended to ensure some measure of commonality of data collection,

[1] The approved list of vital signs was later slightly modified as a result of peer review by the Science Committee. On September 22-24, the GRYN Science Committee met to discuss and peer review the Network's vital signs list. The SC suggested changes to the organization of the vital signs into categories or functional areas so that the Network might better illustrate the interconnectedness of the selected vital signs. Once the vital signs were categorized in this way, the absence of below ground ecosystems was noted and a suggestion to add below ground biota as a vital sign was adopted by the Technical Committee. In addition, ground water quantity and quality was split into two vital signs. These two changes resulted in a final list of 46 vital signs for consideration in Phase III.

comparability, and consistency in a national program and also serves the purpose of having some common set of information that could be rolled up in some form on a national scale to report to Congress. The required water column parameters include: temperature, specific conductance, pH, and dissolved oxygen. Also, in the absence of a quantitative flow measurement at/near the monitoring site (preferred but not required), at a minimum some qualitative estimate or assessment of flow/discharge (low, medium, high, flood stage, etc.) should also be documented (or a quantitative flow estimate be approximated) at all flowing freshwater monitoring sites. At non-flowing freshwater monitoring sites (lakes, reservoirs, etc.), a qualitative assessment of stage/level of the waterbody should be reported along with some minimum profiling of the water column of the required parameters.

1. Vital Sign: Continuous Water Temperature

Temperature of both water and air is a key field measurement at all monitoring sites and is essential information to water data collection. This is a NPS-WRD core parameter. In general, temperature affects growth, distribution and survival of aquatic organisms. Rates of most physical, chemical, and biological processes are strongly influenced by temperature. Gas-diffusion rates, chemical-reaction rates, and the settling velocity of particles are just a few of the many processes related to water temperature. Numerous aquatic organisms are dependent on certain temperature ranges for optimal health. For example, temperature is a key parameter in assessing the suitability of a water body (e.g. stream) for particular fish species and thus in determining its appropriate beneficial use. Water temperature may indicate thermal pollution and influences. In addition, temperature differences between water sources and seasonal variations of temperature make temperature useful in hydrologic investigations, particularly those that involve the mixing of groundwater and surface water.

Because temporal variation in temperature can be significant, intermittent temperature monitoring can be problematic and use of continuous recording devices is a preferred method of sampling (MacDonald et al. 1991). All temperature measurements should be made and reported in units of degrees Celsius (ºC). All temperature measurements should be reported to the nearest 0.2 ºC when using a thermistor thermometer and to the nearest 0.5 ºC when using a liquid-in-liquid thermometer. Measurement methods will vary dependent on water body type, e.g. flowing, shallow stream; stream too deep or swift to wade; and still water.

2. Vital Sign: Flow/Discharge

Stream discharge is defined as the unit volume of water passing a given point on a stream or river over a given time. This is a NPS-WRD core parameter. Stream discharge is typically expressed in cubic feet per second (cfs) or cubic meters per second (cms) and is based on the continuity equation or velocity-area method $Q = A * V$, where A is the cross sectional area of the stream at the measurement point and V is the average velocity of water at that point. Streamflow measurements are useful for water quality data comparisons over time, interpretation of water quality data, and calculation of parameter load. Measurements of discharge are also useful in expaining water quality variablity. Relationships between water quality measures and discharge can often be used to remove (to some degree) the influence of discharge on variablity over time.

Several methods exist for measuring discharge but most methods share several similar steps. They include selection and calibration of a current meter or other means of determining velocity, proper site selection, dividing the channel cross-section into equal increments (usually 25 or more), making the current measurements (by meter or other means) at several points in the vertical while allowing enough time for the device to stabilize (40 seconds for most current meters), determining the mean velocity at each vertical, tabulating the data in field notes, making field computations using the tabulated data, and field checking the computations with an alternate, usually more approximate measurement method (e.g. float method). For service wide consistency and where feasible, NPS-WRD recommends that computations of flow be in English units and reported in cubic feet per second.

3. Vital Sign: Water Chemistry

Water chemistry reflects the effects of precipitation chemistry and amount, and the hydrological/geochemical processes in a watershed. Water chemistry commonly changes as the sources of water change. The chemical composition of natural water is derived from many different sources of solutes, including gases and aerosols from the atmosphere, weathering and erosion of rocks and soil, biological processes in terrestrial systems, and cultural effects resulting from human activities. Assessments of chemical concentrations serve as direct measures of stressors to aquatic life and human health. Chemical-specific data and water quality models allow predictions of the likelihood of impacts to aquatic life and human health where they may not yet have occurred. Information from these analyses is used to evaluate stream condition with respect to stressors such as acidic deposition, nutrient enrichment, climate change and other inorganic contaminants. In addition, streams can be classified with respect to water chemistry type, water clarity, mass balance budgets of constituents, temperature regime, and presence of anoxic conditions. Such data contribute to the understanding of the combined influences of atmospheric deposition, climate, geology and geothermal activity on surface water chemistry and resultant effects on biota. Temperature, pH, conductivity, and dissolved oxygen (four of the NPS-WRD designated core parameters), are usually included in water chemistry.

Specific metrics may include alkalinity, acid neutralizing capacity (ANC), Ca, Mg, Na, K, H^+, Cl, NO_3, SO_4, SRP, TNP, Si, DOC, NH_4, TKN, and others, usually measured in micro or milligrams per liter. Concurrent discharge measurements would allow data to be flow rated.

This vital sign, water chemistry, is an umbrella type indicator and may include a variety of parameters, depending upon parent material, water body type, and stressor evaluation. For water chemistry to be useful as a vital sign, there must be a clear linkage between the chemical paramter of interst and an identified or supected stressor(s). Some of the more common parameters included in water chemistry are detailed below.

<u>pH</u>

The pH value is the negative logarithm of the hydrogen ion (H^+) activity in the water. This is a NPS_WRD core parameter. Values may range from pH 1 to pH 14, with pH 7 neutral, less than 7 acidic and greater than 7 basic. Each pH unit represents a tenfold change in H^+ activity (NPS 1998c). The importance of pH as a parameter for monitoring is reflected by potential impacts to the life cycle stages of aquatic macroinvertebrates and certain salmonids that can be adversely affected when pH levels above 9.0 or below 6.5 occur. The mobility of many metals is also enhanced by low pH and that can play a significant factor in impacts to water bodies located in areas contaminated by heavy metals (e.g. mining). Estimating the toxicity of ammonia, aluminum, and some other contaminants requires accurate pH values as metadata. Temporal causes of variation of pH can range from primary production by fauna and flora (diurnal and seasonal) to fractionation during snowmelt, changes in runoff processes, and changes in atmospheric deposition (monthly and/or seasonal) (MacDonald et al. 1991).

The measurement of pH requires a sensing electrode for H^+, a reference electrode, a meter to measure the electrode potential, and buffers to calibrate the system. In-situ measurement of pH is recommended for surface waters because the pH of a water sample can change significantly within minutes as a result of degassing, precipitation, or temperature change etc. Reporting of all pH measurements should be in pH units as that is the standard unit of measurement for pH. Measurements of pH should be reported to nearest 0.1 standard pH unit for data entry. Measurement of pH in dilute, poorly buffered waters may require special techniques (Turk 1986, Turk 1988)

Specific Conductance

Conductivity or specific electrical conductance is a measure of the capacity of water (or other media) to conduct an electrical current. This is a NPS-WRD core parameter. When the raw conductivity measurement of a substance is normalized to unit length and unit cross-section at a specified temperature (e.g. a compensation temperature of 25 °C), it is specific conductance. Specific conductance is dependent upon the types and quantities of dissolved substances. As concentrations of dissolved ions in water increase, specific conductance increases. The electrical conductivity of a water body has little or no direct effect on aquatic life but because it is essentially due to the sum of all ionic species, its change (increase) may be detrimental if the particular ionic species or groups of ionic species (e.g. salts) causing the change is toxic to aquatic life. Conductivity often varies with flow and is therefore particularly important where flow is not measured. Specific conductance can serve as a surrogate for total dissolved solids and is often best used as an early indicator parameter in baseline monitoring with more specific measurements of individual ions to determine cause and effect in follow-up sampling (MacDonald et al. 1991).

Specific conductance is reported in micromhos/centimeter (μmhos/cm) or milliSiemens/meter (mS/m). Rather precise field measurements of specific conductance can be made with a specific conductance meter. Conductance is dependent upon water temperature, and by convention, values are adjusted to 25°C (standard temperature and pressure). It is recommended that specific conductance measurements be made in-situ whenever possible to minimize the changes that are possible from the loss/gain of dissolved gases, solute precipitation, adsorption, ion exchange etc. that can occur when measurements are performed on a subsample. Specific conductance measurements in flowing surface water should represent the cross-sectional mean or median value at the time of observation.

Dissolved Oxygen

Dissolved oxygen (DO) is a measure of the amount of oxygen in solution. This is a NPS-WRD core parameter. Oxygen solubility is controlled by solution temperature and the partial pressure of oxygen within gasses in contact with the solution. Adequate DO is necessary to maintain diverse aquatic communities and fisheries. Dissolved oxygen is influenced by photosynthetic and microbiologic activity and can be subject to significant daily variation. Water quality monitoring programs that include DO should consider these influences (NPS 1998c). Five milligrams per liter (mg/l) is currently believed to be the minimum level required for maintenance and survival of most aquatic organisms. One mg/l is equivalent to one part per million (ppm). Trout and other coldwater fish require a minimum of 6 to 7 mg/l dissolved oxygen. However, DO concentrations above 110% can be lethal to aquatic life (Wyoming DEQ 1999 and revisions).

Dissolved oxygen (DO) should be measured in-situ or in the field, as concentrations may show a large change in a short time if the sample is not adequately preserved. Dissolved oxygen concentrations may be determined directly with a DO meter or by a chemical method. The method chosen will depend on a number of factors including the accuracy and precision required, convenience, equipment and personnel available and expected interferences.

Alkalinity

> **Note:** [NPS-WRD adopts the USGS/NAWQA definition of alkalinity and ANC for use in the NPS Vital Signs monitoring program. Thus, alkalinity will refer to a filtered water's ability to neutralize acid whereas ANC will refer to the alkalinity of an unfiltered water sample (i.e. alkalinity due to both dissolved and suspended matter)].

Alkalinity is the capacity of a water to neutralize an acid to a specified pH (typically pH 4.5). Generally, alkalinity is a measurement of carbonate, bicarbonate and hydroxide (can also include borates, phosphates or silicates) content of a water. It is typically reported as mg/L $CaCO_3$ or milliequivalent/liter (meq/L) HCO_3^- -C and is usually the dominant anion. Waters of higher alkalinity or buffering capacity due to an abundance of carbonate, bicarbonate, hydroxyl or other species that act as a base, tend to be less susceptible to effects of acid deposition, acid mine drainage, or other anthropogenic acid inputs.

Field determinations of alkalinity and ANC are recommended. The measurement of alkalinity and ANC and concentration of bicarbonate, carbonate, and hydroxide species are determined using either the inflection point titration (IPT) method or the Gran function plot (Gran) method to analyze the titration data.

Acid Neutralizing Capacity

Acid neutralizing capacity refers to the capacity of a water to neutralize an acid to a specified pH endpoint. ANC is the acid-neutralizing capacity of solutes plus particulates in an unfiltered water sample, reported in equivalents per liter (or milliequivalents or microequivalents per liter). ANC is equivalent to alkalinity for samples without titratable particulate matter. ANC differs from alkalinity since the pH equivalence point is determined analytically rather than fixed (i.e. pH 4.5) in order to more accurately describe the capacity of a water to neutralize the H^+ ion. ANC is measured for waters with very low alkalinity. Acid sensitive waters generally have specific conductance below 25 u (micro) S/cm, acid neutralizing capacity (ANC) below 100 ueq/l for episodic acidification (50 ueq/l for chronic acidification), total base cation (calcium, magnesium, sodium, and potassium) concentration below 100 ueq/l, and pH below 6.0. Some references state that surface waters with ANC less than or equal to 200 µeq/L are considered sensitive to acidification (Turk and Spahr 1989).

Waters of low alkalinity (<100 µeq/L) usually require a Gran titration since the equivalence pH is often higher than 4.3 and conventional titration tends to overestimate solution alkalinity (Gran, 1952). ANC is reported as microequivalent/liter (µeq/L) HCO_3^- -C.

Chloride

Chloride (Cl^-) is the only common oxidation state for the element chlorine. Because conductivity is a required parameter, chloride is often not an essential parameter to measure unless there is some site-specific reason to monitor it. Chloride is a chemical component of common rock-forming minerals and consequently is present in various concentrations in surface water primarily depending upon chloride content of meteoric waters, an areas rock type, and anthropogenic inputs. Sedimentary rocks, particularly evaporites, are a principal source of naturally occurring chloride ion in some surface waters (NPS 2003b). Chloride (Cl^-) occurs naturally in streams. Wyoming streams generally contain low ambient chloride concentrations (<25 mg/l). However, some streams which drain areas high in natural salts will have higher ambient chloride levels. Stream chloride concentrations may increase due to introduction of oilfield produced water, industrial and municipal effluent, irrigation returns and low flow. Macroinvertebrates are sensitive to elevated chloride concentrations. Chloride values above 565 mg/l showed well defined impairment to the macroinvertebrate community structure (WY-DEQ 1999).

Chloride is a major anion and most accurately measured in the lab along with the analysis of other major ions. Chloride concentration is generally determined using titrimetric techniques or ion chromotography.

Hardness

Hardness is defined as the capacity of a water to precipitate or waste soap. It is generally associated with the concentration of Ca and Mg in a water but includes any polyvalent cation. It is also important in that some metals, such as copper and zinc, may be more toxic when hardness is low.

Hardness is typically reported in mg/L $CaCO_3$.

Nitrogen, ammonia dissolved

Dissolved ammonia is the reduced form of nitrogen in solution. Ammonia is a highly soluble, colorless, gaseous compound and can exist as NH_3 or NH_4^+ (ammonium ion) depending on solution temperature and pH. Ammonia and related oxidized nitrogen compounds are a major limiting nutrient in most aquatic systems an increase of which may result in eutrophication. The presence of dissolved ammonia is typically indicative of agricultural pollution or anaerobic degradation of nitrogen containing compounds.

Nitrogen, nitrate

Nitrate is the oxidized form of aqueous nitrogen reported as mg/L NO_3 or mg/L NO_3 - N. Nitrogen is a major limiting nutrient in most aquatic systems an increase of which may result in eutrophication. Typically indicative of agricultural pollution. Nitrate also results from atmospheric deposition and is related to episodic acidification. The drinking water standard is 10 mg/L Nitrate also travels freely through soil and therefore may pollute ground waters. Nitrate is measured by ion chromotography.

Nitrite is rare in wildland waters, but in a polluted environment an analysis for nitrate + nitrite may be more appropriate.

Nitrogen, Kjeldahl

Kjeldahl nitrogen is equal to the sum of the nitrogen contained in the free ammonia (NH_3) and other nitrogen compounds which are converted to ammonium sulfate [$(NH_4)_2 SO_4$] under specific digestion conditions. Nitrogen is a major limiting nutrient in most aquatic systems an increase of which may result in eutrophication. Typically indicative of agricultural pollution.

The Kjeldahl nitrogen analysis determines the nitrogen in the trinegative state. If ammonia nitrogen is not removed as the initial procedure, the term Kjeldahl nitrogen is applied to the result. Should Kjeldahl nitrogen and ammonia nitrogen be determined individually, organic nitrogen is calculated as the difference (APHA 1992). The procedure requires an acid digest and should be left to a laboratory for analysis or requires a Kjeldahl digestor.

Kjeldahl nitrogen is a parameter being phased out by the USGS.

Phosphorus (P), orthophosphate

Phosphorous is frequently a limiting nutrient in aquatic systems. A minor increase in phosphorous concentration can significantly affect water quality. The term orthophosphate is a chemistry based term that refers to the phosphate molecule only. Reactive phosphorous is a method based term that describes what is measured when testing for orthophosphate. The technique used measures soluble reactive phosphorous (SRP), which is as close as we can get ot biologically available inorganic P. Sources of phosphorous include: sediments, fertilizer application (e.g. irrigation return flow), cleaning and laundry soaps and detergents.

Phosphorus, total dissolved

This measure of phosphorus includes orthophosphate, condensed phosphates (acid-hydrolyzable) and organically bound phosphates. It is reported as equivalent orthophosphate in mg/L PO_4^{3-}. Phosphorus is frequently a limiting nutrient in aquatic systems and exceedances of standards are generally indicative of agricultural pollution.

Solids, total dissolved

Total dissolved solids (TDS) is operationally defined as the quantity of material not retained by a filter of pore size 0.45 micron average diameter, and is typically reported in mg/L. The principal ions contributing to TDS are carbonate, bicarbonate, chloride, sulfate, nitrate, sodium, potassium, calcium, and magnesium (World Health Organization 1984). TDS therefore is a reflection of these inorganic substances in water. Specific conductance provides a quick indication of a water sample's TDS. In many samples, the specific conductance measurement multiplied by from 0.55 to 0.9 will provide an estimation of TDS (the factor depends on the particular water).

Sulfate, dissolved

Dissolved sulfate refers to the concentration of the oxidized form of aqueous sulfur in water. Sources may include acid mine drainage (oxidization of sulfide minerals) and acid precipitation. The sulfate ion is reported to cause cathartic action in humans at a concentration above 250 mg/L. High sulfate concentration also contributes to poor water taste in the presence of sodium and magnesium.

Trace Metals/ Toxics

If metals or toxic organics or other hazardous substances (such as PCBs) are causing impairment, they will need to be measured. Trace metals are generally defined as metallic elements analyzed using ICP. Includes Al, As, Sb, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, Se, Ag, Th, Va, Zn. For routine (not very low level) monitoring, EPA ICP method 200.7 is usually used (USEPA 1994a); 200.7 will also suffice for many routine I&M level monitoring applications. Although parks are encouraged to use ICP methods for routine I&M monitoring for other metals, there are times when they will want to use more rigorous methods, and they are encouraged to do so in those cases.

4. Vital Sign: River Invertebrate Assemblages

Benthic invertebrates inhabit the sediment or live on the bottom substrates of streams. Benthic macroinvertebrate assemblages in streams reflect overall biological integrity of the benthic community. Monitoring these assemblages is useful in assessing the status of the water body and detecting trend in ecological condition. Benthic communities respond to a wide array of stressors in different ways so that it is often possible to determine the type of stress that has affected a macroinvertebrate community (e.g., Klemm et al. 1990). Because many macroinvertebrates have relatively long life cycles of a year or more and are relatively immobile, macroinvertebrate community structure is a function of present or past conditions.

5. Vital Sign: Algal Species Composition and Biomass

Algal biomass and species composition may change in response to an increase of nutrients in the food web. These changes may be sensitive indicators to nutrient inputs and associated climate change. Measurements include species composition indices, direct measure of boimass of periphyton and chlorophyll a, and various measures of water clarity.

Water Clarity

One of the major diagnostic tools in the analysis of eutrophication is the measurement of water transparency. Although not usually mentioned in State Water Quality standards, there is often a long historical record of Secchi disk depth reading in lakes and some other deep waters. Whereas turbidity is a measure of light "scatter," sunlight penetration into waters is a distinct aspect of "clarity" that is more closely related to light absorption. Algal blooms decrease light penetration by light absorption, and scattering water transparency and light penetration are proportional to the density of the algal bloom.

A simple method of estimating light penetration in the vertical direction is with a Secchi disk, where the disappearance depth is defined as the Secchi depth. Both the Secchi and black disks have a precision of about 4%. The black disc has some advantages that may avoid biases, related to the fact that it (ideally) reflects no light and is therefore (almost) independent of ambient lighting.

See, also, Turbidity, under the vital sign Stream Sediment Transport

Chlorophyll a

Chlorophyll is a key biochemical component in the molecular apparatus that is responsible for photosynthesis and is found in various forms within the living cells of algae, phytoplankton, and other plant matter of water environments. Like other biological response variables, chlorophyll a tends to integrate the stresses of various parameters over time, and thus is often an important nutrient-stress parameter to measure. The amount of chlorophyll in a water sample is a general measure of the concentration of suspended phytoplankton that also can be used as an indicator of water quality.

The three methods for determination of chlorophyll a in phytoplankton are: spectrophotometric, fluorometric and high-performance liquid chromatography (HPLC). Fluorometry is more sensitive than spectrophotometry requires less sample and can be used for in-vivo measurements. These optical methods can significantly under- or overestimate chlorophyll a concentration due to overlapping absorption and fluorescent bands (APHA 1992).

Periphyton

Periphyton are useful indicators of environmental condition because they respond rapidly and are sensitive to a number of anthropogenic disturbances, including habitat destruction, contamination by nutrients, metals, herbicides, hydrocarbons, and acidification (e.g., Hill et al. 2000). Benthic algae (periphyton or phytobenthos) are primary producers and an important foundation of many stream food webs. These organisms also stabilize substrata and serve as habitat for many other organisms. Because benthic algal assemblages are attached to substrate, their characteristics are affected by physical, chemical, and biological disturbances that occur in the stream reach during the time in which the assemblage developed.

6. Vital Sign: E. coli

Escherichia coli (E. coli) is one type of fecal indicator bacteria that is used for predicting gastrointestinal illness in swimmers based on the density of the indicator organism in bathing waters. Fecal indicator bacteria are used because they are not typically disease causing, but are correlated to the presence of several waterborne disease-causing organisms (pathogens). The concentration of indicator bacteria (the term "indicator bacteria" is used synonymously with fecal indicator bacteria) is a measure of water safety for body contact recreation or for consumption. Wastes from warm-blooded animals contribute a variety of intestinal bacteria that are pathogenic to humans. The presence of *E. coli* in water is direct evidence of fecal contamination from warm-blooded animals and indicates the possible presence of pathogens (Dufour 1977).

The freshwater criterion for *E. coli* in bathing water is a geometric-mean concentration of 126 col/100 mL. (USEPA 1986, p. 15). For potable waters, the detection of 1 col/100 mL of *E. coli* warrant concern for public health.

7. Vital Sign: Reservoir Elevation

"Lakes that are hydrologically managed (e.g. Jackson Lake, Bighorn lake) will have fluctuating water levels that can potentially affect lake food webs and ecosystem function. Lakes are linked to their shoreline and receive a fraction of their energy inputs from allochthonous inputs, coarse woody debris that provides habitat, and may control terrestrial predator interactions (Schindler and Scheuerell 2002). Changing water level may decrease allochthonous inputs and may limit access of the lake by terrestrial predators (e.g. otters)" (Hall 2003). Lake water level is measured in feet or meters.

8. Vital Sign: Groundwater quantity and quality

Groundwater is recharged by infiltration of precipitation, streamflow leakage, irrigation water, and inflow from other aquifers. Groundwater is discharged through pumped wells and is naturally discharged by springs and seeps, by evapotranspiration, and by discharge to streams and other geologic units. The American Institute of Hydrology lists groundwater hydrology as a basic hydrological measurement. Changes in land use can greatly affect the hydrology of groundwater, along with climate change. Monitoring this parameter of water quality is important in spatial and temporal comparisons, as well as the interpretation of overall water quality.

9. Vital Sign: Watershed Budgets

Watershed budgets incorporate and integrate many individual ecosystem indicators that regulate ecosystem functions and services. Watershed characteristics such as size, slope, geological composition, biota and climate all influence a watershed's quantity and quality of water resources, forest production, landscape diversity, trace gas fluxes, soil C storage, erosion, and biodiversity. Therefore, the goal of a "watershed budget" is to understand processes (snow accumulation, atmospheric deposition, snowmelt, hydrologic flowpaths, ground-water/surface-water interactions, rainfall runoff, fluxes of carbon and nitrogen, cation exchange and mineral weathering, and streamflow generation) controlling water, energy, sediment and other biogeochemical fluxes, within the context of atmospheric and climatic variables and within a specified drainage basin. An understanding of controls on spatial and temporal variations on such processes and fluxes is needed to predict ecosystem response to natural and anthropogenic stresses.

In general, a budget integrates physical (e.g. hydrology, temperature, etc.) with biological processes (e.g. vegetation dynamics, soil microbes, stream processing).

10. Vital Sign: Stream Sediment Transport

<u>Solids, total suspended</u>

Total suspended solids (TSS) is operationally defined as the constituents present within a water of a diameter greater than 0.45µM. TSS is typically reported in mg/L. Suspended solids (or “sediment’) often come from from areas of human-caused erosion, such as eroding roads, farm fields, logging areas, and subdivision construction sites. Some of the suspended solids however are natural --the result of normal levels of erosion occurring on land surfaces and along stream environs (e.g., eroding banks). Total suspended solids therefore can be a key indicator of land disturbance in a watershed. TSS data will not be directly comparable with historical suspended sediment concentration (SCC) data collected by the USGS.

Turbidity

Turbidity is an arbitrary (instrument-specific and relative) measure of light scattering, which has a weak correlation with light penetration and a variable correlations (depending on site and flow regimes) or lack thereof with sediment loads. Undissolved, finely distributed solids (organisms, organic materials, suspended sediment, colloidal color) in a water sample are known as suspended solids. These solids scatter and absorb the light beam of a turbidimeter rather than transmitting that light. Sediment loads and factors related to light are both potentially important biological/ecological issues. Turbidity interferes with sunlight penetration, which reduces photosynthesis (primary production) by bacteria, algae and periphyton. Turbidity has the potential to cause changes in the macroinvertebrate community structure. High turbidity levels adversely affect feeding and growth of trout by interfering with vision and the capture of food organisms.

The field measurement is preferable, since some of the particulate matter will settle or adhere to the sample container wall during transportation. Furthermore, changes in the pH of the sample may cause the precipitation of carbonates and humic acids, affecting sample turbidity. When the analysis cannot be done immediately, the sample should be stored in the dark and for not more than 24 hours. Turbidity can be measured by visual methods (in Jackson Turbidity Units or JTU) or nephelometric methods (in Nephelometric Turbidity Units or NTU). Nephelometric methods are preferred due to their greater precision, sensitivity and application over a wide turbidity range.

B. Consideration of Target Populations, Study Boundaries, & Sample Units in Choosing Vital Signs.

General I&M guidance suggests that the plan should detail an “overall statistical sampling design that allows inferences to be made about areas larger than those actually sampled” (NPS 2003c). Since one cannot sample everything at all potential sites and all potential times, one typically samples a limited amount of times and locations and then tries to make statistical inferences (conclusions) about the larger target population. It is very important before the sampling design is finalized to determine the “target population” that will be sampled.

If all of park-identified water quality monitoring needs (Appendix G) were to be achieved through the vital signs monitoring program, then water quality monitoring could easily subsume the entire program. There is, therefore, a need for an overall statistical sampling design that allows inferences to be made to areas larger than those actually sampled. Hopefully, the watershed classification project (in progress) will provide information that can be used to help stratify sampling efforts. In addition, the recent water quality data analysis (Woods and Corbin 2003a, b and c) provides summary statistics for 13 parameters of interest.

These estimates will be used to guide the sampling design, in terms of the number of samples required to detect the desired amount of change. As part of the larger Vital Signs Monitoring Program, it is essential that the water quality monitoring be closely coordinated with the monitoring of other selected vital signs to allow for collocation of sample sites.

C. Identification of Decisions and Decision Rules

In general, the WQWG decided that exceedances of state standards could be used as trigger points for management action. In almost all cases, the initial management action would be to determine the cause of the exceedance. For YELL, it will be important to identify those waters which are geothermally influenced, as the state standards may not be applicable.

The following are considered by the state of Montana to constitute overwhelming evidence of human-caused impairments (Montana DEQ 2002g), and could be revised by the GRYN for use as decision rules:

- Any exceedance of an acute aquatic life standard.
- A 250% exceedance of a chronic aquatic life standard, even if there is only one credible data point.
- Any exceedance of an aquatic life standard based on sufficient data to calculate a geometric mean.
- Any 50% exceedance of a narrative standard (e.g. sediment levels in an impaired stream reach are determined to be 50% greater than sediment levels of an appropriate reference site).
- Any activities that negatively impact habitat by more than 50% (e.g. less than 50% of a stream corridor has adequate riparian habitat when compared to potential or reference condition).
- Any activities that negatively impact biological communities by more than 50% (e.g. a fish population reduced to less than 50% of its potential due to sedimentation; or macroinvertebrate communities less than 50% of those in reference waters).

D. Summary of Results of Peer Review of Phase II

On December 3, 2003, the GRYN Phase II Water Quality Monitoring Plan was sent out for peer review to the GRYN Technical Committee, members of the former Water Quality Work Group, and the following subject matter experts:

Robert O. Hall, Jr., Department of Zoology and Physiology, University of Wyoming
Donald H. Campbell, U.S. Geological Survey, Denver CO
Bill Jackson, National Park Service, Water Resources Division, Fort Collins, CO
Myron Brooks, USGS, District Chief, Water Resources Division, Cheyenne, WY
Dixon H. Landers Ph.D., Sr. Research Environmental Scientist (Limnology), U. S. EPA

Comments were requested back by close of business December 22, 2003. Reviewers were asked to respond to the following general questions related to the context of the Plan:

1. Does the plan adequately describe why parks are monitoring “vital signs”?

2. Does the plan answer the question “who is interested in the information provided by monitoring and why”?
3. Does the plan adequately describe the water resources in each of the network parks? Are impaired or pristine water adequately identified?
4. Does the plan adequately identify the sources of pollution and other suspect stressors for each of the network parks?
5. Does the plan adequately describe historical/existing water quality monitoring efforts in each of the network parks?
6. Does the plan adequately describe how the monitoring objectives for impaired waters were developed? Are these objectives sufficient to address monitoring needs?

Comments were received from all of the subject matter experts as well as from the GRYN Program Manager, GRTE Chief of Science and Resource Management and YELL Aquatic Ecologist, Jeff Arnold.

In general, the comments can be divided into four categories: 1) comments that are basically editorial in nature; 2) comments that relate directly to descriptions of selected vital signs; 3) comments related to the accuracy of information contained in the document; and 4) comments related to tables and/or figures. Most of the editorial comments, and a few of the others, have been incorporated into the text of this final document. All of the comments, in table form, appear in Appendix L.

Other comments (those not editorial in nature) are without a doubt of far greater significance, and are considered to be critically important as the GRYN moves into Phase 3 of the Vital Signs Monitoring Program. For example, Bill Jackson’s comment that “a table listing each water body of interest, known parameter exceedances for each waterbody of interest, potential land uses that might be causing exceedances (on impaired waterbodies), and other potential threats and their potential indicators (both impaired and pristine waters) would really help pull some of this information together for the reader,” provides guidance and future direction for developing our water quality monitoring objectives for pristine and other waters. Dixon Landers provides excellent insight into the development of a robust sampling design for a long-term monitoring program. Don Campbell has provided well thought out suggestions for improving the GRYN’s descriptions of water quality related vital signs.

It is hoped that all of the comments will be successfully integrated into the GRYN’s Phase III process.

This, and subsequent sections are incomplete.
They will be completed as part of the GRYN's Phase III process.

V. Sampling Design

With the selection of the GRYN's vital signs list complete, the Network will focus on developing monitoring objectives, followed by sampling design and sampling protocols. Based on the synthesis of information, the review of existing data, and clearly defined monitoring objectives, sampling designs will be developed that meet the requirements described by Hinds (1984) of being ecologically relevant, statistically sound, and cost effective.

A. Proposed Sampling Design to Answer Questions

B. Proposed Statistical Analyses To Be Used

C. Data Quantity Objectives and Statistical Power

D. Data Representativeness, A QC Data Quality Indicator

VI. Sampling Protocols

A. Data Comparability

Both Wyoming and Montana have "credible data" requirements for water quality data. Vital Signs long-term water quality monitoring projects will be designed to:

1. satisfy the states' credible data requirements;
2. consider well established sampling protocols (USEPA 1974; Lind 1979; Wetzel and Likens 1991; APHA 1995, USGS 1997-1999); and
3. allow data to be shared across agency boundaries. Similarly, Vital Signs' water quality monitoring data will be entered into EPA's new STORET database (at least annually), which is compliant with Clean Water Act metadata requirements.

The USGS National Water Information System (NWIS) database (USGS 2003) will also be used by the GRYN and its data will be made available to parks and networks.

A.1 Standard Operating Procedures (SOPS), Standard Methods, and Standard Protocols Selected to Optimize Data Comparability

In general, the NPS-WRD recommends using the protocols of the USGS NAWQA program. For regulatory monitoring, monitoring protocols of individual states will be consulted for supplemental guidance. Most states have developed water quality monitoring protocols. These serve to support their establishment of lists of impaired water bodies within their jurisdiction (303d lists), aid in the identification of outstanding natural resource waters, facilitate implementation of permits under the National Point Discharge Elimination System (NPDES) program and initiate the development of Total Maximum Daily Load studies.

A.2 Selecting a Chemical Lab

A.3 Selecting a Project Leader

B. Measurement Sensitivity, Detection Limits, And Calibration

C. Data Completeness

D. Field Measurement Precision

E. Lab Measurement Precision

F. Lab Measurement Systematic Error (Bias)

G. Field Measurement Systematic Error (Bias)

H. Blank Control Systematic Error (Bias)

I. Uncertainty In Accuracy Control

VII. Data Management

Vital Signs Monitoring Networks will be collecting a wide variety of physical, chemical, biological, and other data in support of monitoring impaired, pristine, and other high-priority waters. All water quality data collected by Vital Signs Monitoring Networks will be funneled through the NPS Water Resources Division into the Environmental Protection Agency's (EPA) modernized STORET (STOrage and RETrieval) database where the data will be available to parks, Regions, and the public on the Internet. At a minimum, the results provided must follow the "Data Elements for Reporting Water Quality Results of Chemical and Microbiological Analytes" developed by the National Water Quality Monitoring Council (http://wi.water.usgs.gov/pmethods/elements/elements.html). These data elements document the "**W**ho, **W**hat, **W**here, **W**hen, **W**hy, and **H**ow" of the monitoring effort.

Water quality data will be entered into STORET through a series of input screens (forms/templates) developed by the NPS-WRD. This will provide one approach for Vital Signs Monitoring Networks to enter data about their projects, stations, results, and metadata.

A. Data Management And Handling

B. Data Reporting And Archiving

VIII. Data Analysis and Reporting

A. Responsibility

B. Frequency

C. Reports

IX. Administration/Implementation of the Monitoring Program

A. General Documentation

B. Project Management, Staff Qualifications, And Staff Training

X. Schedule

A. Sampling Frequency (for each component)

B. Protocol Development Target Dates

XI. Budget

XII. Study Optimization

A. Summary Of Steps Taken To Bound Minimum Measurement Uncertainty

B. Summary Of Steps Taken To Bound Model, Study Design, And Software Uncertainty

C. Summary Of Issues Considered In Final Study Design Optimization Step

D. Brief Description Of Plan To Implement Pilot Scale Monitoring

E. Brief Description Of Who Will Revise The Plan Following Pilot Scale Monitoring And When Long-Term Monitoring Will Begin

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XIV. Appendices

APPENDIX A. Summary of water quality questionnaire completed by park personnel

Table 3. Summary of water quality questionnaire (BICA).

WATER BODIES CRITICAL TO THE PURPOSE OF THE PARK

Bighorn Canyon National Recreation Area

WATER BODY	MANAGEMENT USES	CONDITION	THREATS
Bighorn Lake	Fish habitat, scenic resource, recreational use, overall	Perceived to be threatened in the short term	Pesticides, fecal contamination, nutrient loading, sediment loading, heavy metal contamination, noxious weed seeds
Ponds on Yellowtail Habitat	Wildlife habitat, riparian zone	"impaired" in the park's perspective	Noxious weeds, tamarisk
Layout Creek	Wildlife habitat, scenic resource, riparian zone	"impaired"	Cattle trailing. Noxious weeds, tamarisk
Trail Creek	Wildlife habitat, scenic resource, recreational use	"impaired"	Cattle trailing, noxious weeds, tamarisk
Springs in Dryhead	Fish habitat, overall	"impaired"	

Table 4. Summary of water quality questionnaire (YELL).

WATER BODIES CRITICAL TO THE PURPOSE OF THE PARK

Yellowstone National Park

WATER BODY	MANAGEMENT USES	CONDITION	THREATS
Yellowstone Lake	Fish habitat, T&E, recreational use, importance for native species, overall	"impaired" in the park's perspective; perceived to be threatened in the long and short term	Invasive exotics, boaters (pollution, exotics, aesthetics), anglers (interbasin biota transport, degraded shoreline), fire suppression (exotic transport)
Heart Lake	Fish habitat, T&E, importance for natives	"impaired" in the park's perspective; perceived to be threatened in the long and short term	
Yellowstone River above the falls	Fish habitat, T&E, recreational use, riparian zone, importance for natives, overall	Pristine, perceived to be threatened in both the long and short term	Threatened by sewage spills, whirling disease, mud snails
Lewis Lake	Importance for natives	"impaired" in the park's perspective; perceived to be threatened in the long and short term	

WATER BODIES CRITICAL TO THE PURPOSE OF THE PARK

Yellowstone National Park

WATER BODY	MANAGEMENT USES	CONDITION	THREATS
Madison River	Fish habitat, T&E, recreational use, riparian zone	"impaired" in the park's perspective; perceived to be threatened in the long and short term	Non-natives, mud snails, whirling disease, high public use, sewage outflow
Firehole River	Recreational use, riparian zone	"impaired" in the park's perspective; perceived to be threatened in the long and short term	Roads (sedimentation), anglers, invasive exotics
Gibbon River	T&E, recreational use, riparian zone, importance for natives, overall	"impaired" in the park's perspective; perceived to be threatened in the long and short term	Roads (sedimentation), anglers, invasive exotics
Lamar River	Fish habitat, T&E, recreational use, riparian zone, importance for natives, overall	Potentially threatened in the long term	Roads (sedimentation), anglers, invasive exotics Threatened by grazing of elk/bison
Soda Butte River	Fish habitat, T&E, riparian zone, importance for natives, overall	"impaired" in park's perspective	Roads (sedimentation), anglers, invasive exotics, Mine outside park altered water chemistry, road project recovery

WATER BODIES CRITICAL TO THE PURPOSE OF THE PARK

Yellowstone National Park

WATER BODY	*MANAGEMENT USES*	*CONDITION*	*THREATS*
Gallatin River	Fish habitat, T&E, riparian zone, importance for natives, overall	"impaired" in the park's perspective, potentially threatened in the long term	Roads (sedimentation), anglers, invasive exotics Non-native species present
Snake River	Fish habitat, T&E, riparian zone	"impaired" in the park's perspective, potentially threatened in the long term	Roads (sedimentation), anglers, invasive exotics Non-native species and mud snails
Bechler River	Riparian zone	"impaired" in the park's perspective	Roads (sedimentation), anglers, invasive exotics Non-native species (rainbow trout)
Gardiner River	Fish habitat, recreational use, riparian zone	"impaired" in the park's perspective; perceived to be threatened in the long and short term	Roads (sedimentation), anglers, invasive exotics Based on presence of non-natives, road construction, public use

Table 5. Summary of water quality questionnaire (GRTE).

WATER BODIES CRITICAL TO THE PURPOSE OF THE PARK

Grand Teton National Park

WATER BODY	MANAGEMENT USES	CONDITION	THREATS
Jackson Lake	Fish habitat, wildlife habitat, T&E, scenic resource, recreational use, overall	Perceived to be potentially threatened in the long term	Recreational use, pollution, introduced species, level under control of dam
Snake River	Fish habitat, wildlife habitat, T&E, scenic resource, recreational use, riparian zone and floodplain, overall	Perceived to be potentially threatened in the long term	Noxious weed transport, introduced species, rafting pressure, diversions, dam, fishing pressure, development
Backcountry creeks (western tributaries to Snake)	Fish habitat, wildlife habitat, scenic resource, recreational use, overall	Perceived to be potentially threatened in the long term	Fecal coliform
Eastern tributaries to Snake	Fish habitat, wildlife habitat, scenic resource, riparian zone	Perceived to be potentially threatened in the long term	Grazing, irrigation, development
Alpine lakes	Wildlife habitat, scenic resource, overall	Perceived to be potentially threatened in the long term	Atmospheric deposition, introduced species

APPENDIX B. Water quality standard exceedances for the GRYN

Table 6. Historical water quality standard exceedances (from database developed by Woods and Corbin 2003a, b, and c).

PARK	PARAMETER GROUP	PARAMETER	No. of EXCEEDANCES
Bighorn Canyon	Bacteriological	"COLIFORM,TOT,MEMBRANE FILTER,IMMED.M-ENDO MED,35C"	16
		"COLIFORM,TOT,MPN, CONFIRMED TEST, TUBE CONFIG."	4
		"COLIFORM,TOT,MPN,CONFIRMED TEST,35C (TUBE 31506)"	40
		"FECAL COLIFORM, MF,M-FC, 0.7 UM"	167
		"FECAL COLIFORM,MEMBR FILTER,M-FC AGAR,44.5C,24HR"	18
		"FECAL COLIFORM,MEMBR FILTER,M-FC BROTH,44.5 C"	26
		"FECAL COLIFORM,MPN,EC MED,44.5C (TUBE 31614)"	28
		"FECAL COLIFORM,MPN,TUBE CONFIGURATION"	70
	Clarity/Turbidity	"TURBIDITY, (JACKSON CANDLE UNITS)"	298
		"TURBIDITY,HACH TURBIDIMETER (FORMAZIN TURB UNIT)"	36
		"TURBIDITY,LAB NEPHELOMETRIC TURBIDITY UNITS, NTU"	22
	Dissolved Oxygen	"OXYGEN ,DISSOLVED, ANALYSIS BY PROBE MG/L"	42
		"OXYGEN, DISSOLVED MG/L"	47
	Nitrate/Nitrogen	"NITRATE NITROGEN, DISSOLVED (MG/L AS NO3)"	4
		"NITRITE NITROGEN, DISSOLVED (MG/L AS NO2)"	72
		"NITRITE PLUS NITRATE, DISS. 1 DET. (MG/L AS N)"	2
	pH	PH (STANDARD UNITS)	4
	Sulfates	"SULFATE, TOTAL (MG/L AS SO4)"	1823
	Toxic Elements	"ALUMINUM, DISSOLVED (UG/L AS AL)"	23
		"ARSENIC, DISSOLVED (UG/L AS AS)"	4
		"ARSENIC, TOTAL (UG/L AS AS)"	2
		"BERYLLIUM, TOTAL (UG/L AS BE)"	16
		"CADMIUM, DISSOLVED (UG/L AS CD)"	18
		"CADMIUM, TOTAL (UG/L AS CD)"	4
		"CHROMIUM, DISSOLVED (UG/L AS CR)"	2
		"COPPER, DISSOLVED (UG/L AS CU)"	138
		"COPPER, TOTAL (UG/L AS CU)"	33
		"IRON, DISSOLVED (UG/L AS FE)"	7
		"LEAD, DISSOLVED (UG/L AS PB)"	118
		"MANGANESE, DISSOLVED (UG/L AS MN)"	1
		"MANGANESE, TOTAL (UG/L AS MN)"	58
		"MERCURY, DISSOLVED (UG/L AS HG)"	47
		"MERCURY, TOTAL (UG/L AS HG)"	24
		"NICKEL, DISSOLVED (UG/L AS NI)"	41

		"NICKEL, TOTAL (UG/L AS NI)"	1
		"P,P'-DDE DISSUG/L"	41
		"SILVER, DISSOLVED (UG/L AS AG)"	20
		"URANIUM, NATURAL, DISSOLVED"	16
		"URANIUM, NATURAL, SUSPENDED"	2
		"ZINC, DISSOLVED (UG/L AS ZN)"	82
		"ZINC, TOTAL (UG/L AS ZN)"	48
		DDE IN SUSP. FRAC. OF WATER SAMPLE (UG/L)	2
		DDE IN WHOLE WATER SAMPLE (UG/L)	2
		DDT IN WHOLE WATER SAMPLE (UG/L)	3
		DIELDRIN IN FILT. FRAC. OF WATER SAMPLE (UG/L)	45
		DIELDRIN IN WHOLE WATER SAMPLE (UG/L)	4
Grand Teton	Alkalinity	"ALKALINITY,TOTAL,LOW LEVEL GRAN ANALYSIS UEQ/L"	3
	Bacteriological	"COLIFORM,TOT,MEMBR FILTER,DELAYED,M-ENDO MED,35 C"	6
		"COLIFORM,TOT,MPN, CONFIRMED TEST, TUBE CONFIG."	2
		"COLIFORM,TOT,MPN,COMPLETED TEST,35C (TUBE 31508)"	6
		"FECAL COLIFORM, MF,M-FC, 0.7 UM"	2
		"FECAL COLIFORM,MEMBR FILTER,M-FC BROTH,44.5 C"	1
		"FECAL COLIFORM,MPN,EC MED,44.5C (TUBE 31614)"	4
		"FECAL COLIFORM,MPN,TUBE CONFIGURATION"	2
	Clarity/Turbidity	"TURBIDITY, (JACKSON CANDLE UNITS)"	3
		"TURBIDITY,HACH TURBIDIMETER (FORMAZIN TURB UNIT)"	27
	Dissolved Oxygen	"OXYGEN, DISSOLVED MG/L"	59
	Nitrate/Nitrogen	"NITRITE PLUS NITRATE, DISS. 1 DET. (MG/L AS N)"	1
	pH	"PH, FIELD, STANDARD UNITS SU"	198
		"PH, LAB, STANDARD UNITS SU"	293
		PH (STANDARD UNITS)	113
	Sulfates	"SULFATE, TOTAL (MG/L AS SO4)"	5
	Toxic Elements	"ALUMINUM, DISSOLVED (UG/L AS AL)"	54
		"ARSENIC, DISSOLVED (UG/L AS AS)"	43
		"ARSENIC, TOTAL (UG/L AS AS)"	25
		"BERYLLIUM, DISSOLVED (UG/L AS BE)"	1
		"CADMIUM, DISSOLVED (UG/L AS CD)"	12
		"CADMIUM, TOTAL (UG/L AS CD)"	8
		"CHROMIUM, DISSOLVED (UG/L AS CR)"	4
		"CHROMIUM, TOTAL (UG/L AS CR)"	6
		"COPPER, DISSOLVED (UG/L AS CU)"	63
		"COPPER, TOTAL (UG/L AS CU)"	6
		"IRON, DISSOLVED (UG/L AS FE)"	5
		"LEAD, DISSOLVED (UG/L AS PB)"	5

		"LEAD, TOTAL (UG/L AS PB)"	10
		"MANGANESE, TOTAL (UG/L AS MN)"	1
		"MERCURY, DISSOLVED (UG/L AS HG)"	51
		"MERCURY, TOTAL (UG/L AS HG)"	40
		"NICKEL, DISSOLVED (UG/L AS NI)"	8
		"P,P'-DDE DISSUG/L"	25
		"SILVER, DISSOLVED (UG/L AS AG)"	49
		"ZINC, DISSOLVED (UG/L AS ZN)"	48
		"ZINC, TOTAL (UG/L AS ZN)"	8
		DDE IN WHOLE WATER SAMPLE (UG/L)	1
		DDT IN WHOLE WATER SAMPLE (UG/L)	1
		DIELDRIN IN FILT. FRAC. OF WATER SAMPLE (UG/L)	27
Yellowstone	Alkalinity	"ALKALINITY,TOTAL,LOW LEVEL GRAN ANALYSIS UEQ/L"	9
	Dissolved Oxygen	"OXYGEN, DISSOLVED MG/L"	26
	pH	"PH, FIELD, STANDARD UNITS SU"	6
		"PH, LAB, STANDARD UNITS SU"	20
		PH (STANDARD UNITS)	544
	Sulfates	"SULFATE, TOTAL (MG/L AS SO4)"	178
	Toxic Elements	"ALUMINUM, DISSOLVED (UG/L AS AL)"	1
		"ANTIMONY, DISSOLVED (UG/L AS SB)"	5
		"ANTIMONY, TOTAL (UG/L AS SB)"	5
		"ARSENIC, DISSOLVED (UG/L AS AS)"	86
		"ARSENIC, TOTAL (UG/L AS AS)"	139
		"BERYLLIUM, TOTAL (UG/L AS BE)"	9
		"CADMIUM, DISSOLVED (UG/L AS CD)"	17
		"CADMIUM, TOTAL (UG/L AS CD)"	11
		"COPPER, DISSOLVED (UG/L AS CU)"	10
		"COPPER, TOTAL (UG/L AS CU)"	548
		"LEAD, DISSOLVED (UG/L AS PB)"	15
		"LEAD, TOTAL (UG/L AS PB)"	12
		"MANGANESE, TOTAL (UG/L AS MN)"	2
		"MERCURY, DISSOLVED (UG/L AS HG)"	25
		"MERCURY, TOTAL (UG/L AS HG)"	29
		"SELENIUM, TOTAL (UG/L AS SE)"	5
		"SILVER, DISSOLVED (UG/L AS AG)"	5
		"SILVER, TOTAL (UG/L AS AG)"	5

APPENDIX C. Summary of meetings and workshops

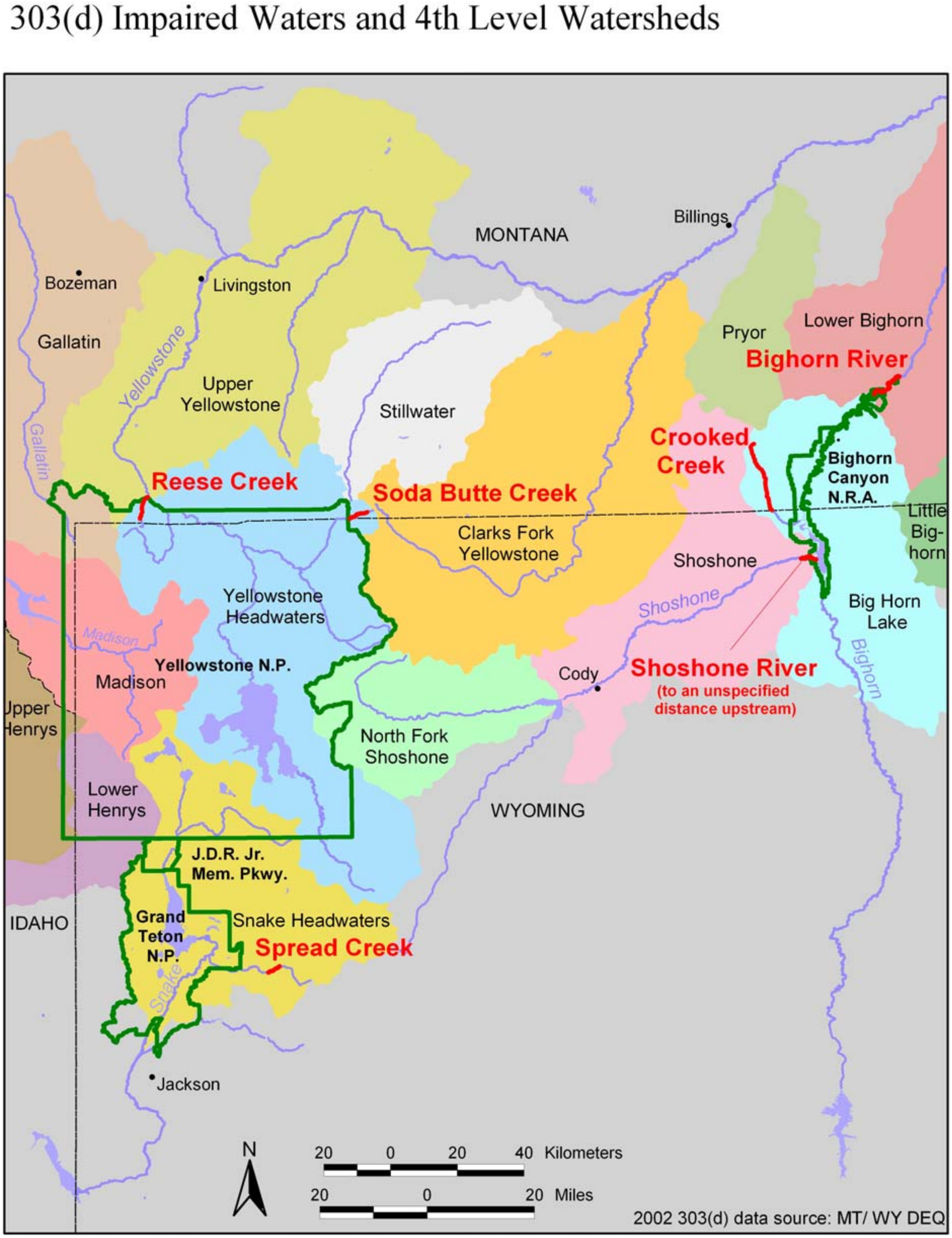
Table 7. Summary of GRYN water quality related meetings.

Date	Location	General Purpose	Outcomes
06/05/01	Mammoth, YELL	Identify park sources and points of contact for current and historic water quality data	Acceptance of water quality "mission statement"; begin implementation of WRD guidance for water quality monitoring plan.
12/5/01	Missoula, MT	Review ramifications of WRD guidance; review U of M task order; review park responses to water quality questionnaire	303d listed waters MUST be addressed in the monitoring plan; updated STORET data will be provided to the Network by WRD staff; responses to questionnaire were very park specific and management oriented
6/25-26/02	Gardiner, MT	State, Federal and Local agencies involved in water quality monitoring invited to discuss what, why and how they are monitoring; review preliminary results of Woods task agreement	Formalize the formation of a GRYN water quality work group; Develop monitoring issues/themes based on Woods' recommendations; Consider in situ monitoring; Develop rfp's for pilot work;
10/28/02	Bozeman, MT	Formalize water quality work group; discuss requests for proposals	Determine topics for proposals for pilot studies; select additional "ad hoc" participants.
12/16/02	Conference call	Discuss current park WQ monitoring; review Delphi II and preliminary Woods' report; discuss emphasis areas	Agreed on 3 different emphasis areas to guide the development of monitoring objectives: In BICA, the emphasis will be on impairment issues and baseline sampling. The emphasis in YELL is a cumulative, integrated monitoring program for a suite of water quality parameters at the watershed level. This would include sampling at major river confluences, locations at the park exit, historic sites on Yellowstone Lake and areas of special concern due to anthropogenic influences such as mining and road construction. The issue addressed in GRTE will be sensitive headwater catchments. These emphases will guide, not limit, GRYN monitoring objectives. They will be used as a means of prioritizing park monitoring needs.
2/16/03	Conference call	Reviewed responses to requests for proposals.	Selected proposals to forward to Technical Committee. Three projects were selected to assist in the final development of specific water quality monitoring objectives for each of the three GRYN parks, and a water quality monitoring plan for the GRYN: 1) Classify the sixth level watersheds in all three parks (GRTE, YELL, and BICA) using characteristics, such as elevation, gradient, basin size, soils, and disturbance, which affect water quality. A representative sample of the streams that drain each of these watersheds may then be randomly chosen for monitoring. Potential stressors to high water quality such as fire, thermal influence, grazing pressure (native and domestic animals), and human activity (campsites, road corridors, mining, drilling) will be created as GIS layers and used as overlays. Sampling schemes can then be developed that compare similar watersheds and are designed to monitor status and trends for an entire

			park or specifically to monitor the effects of known impacts. 2) Develop a color-coded risk assessment map depicting an estimate of aquatic ecosystem sensitivity to atmospheric deposition of pollutants for individual basins will be developed to identify aquatic ecosystems most at risk. Four sensitivity groups will be identified, extremely sensitive (<20 ueq/l ANC), highly sensitive (20-50 ueq/l ANC), moderately sensitive (50-200 ueq/l ANC), low sensitivity (>200 ueq/l ANC). The color-coded maps will be easy to interpret for water management decisions. Data gaps will be identified and potential candidates will be presented for long-term water-quality monitoring of alpine/sub-alpine lakes sensitive to atmospheric deposition of pollutants in GRYN. 3) Document existing ecological problems on Soda Butte Creek through (a) compilation of existing information into a database, and (b) one-time synoptic sampling. A monitoring strategy will be developed based on sampling critical parameters guided by the information from the synoptic sampling to develop "vital signs" that (a) assess the basic health and integrity to guide the decisions of land managers, and (b) do so in a rigorous fashion that can withstand legal challenge.
4/10/03	Conference call	Discussed/developed monitoring objectives for both impaired and pristine waters.	Need further development.
7/03/03	Conference call	Reviewed draft monitoring plan. Provided comments and suggestions for improvement.	Suggestions incorporated into plan
8/07/03	Lake, YELL		Fund macroinvertebrate work; discuss monitoring objectives; agree upon questions to be answered

APPENDIX D. Location of 303(d) listed waters in the Greater Yellowstone Network

Figure 1. GRYN 303(d) impaired waters (from MT-DEQ 2002a and WY-DEQ 2002a). 303(d) waters appear in red. 4th level watersheds are represented by different colored polygons.



APPENDIX E. Location of current and historic water quality monitoring stations

Figure 2. Historic and current water quality monitoring locations in BICA (from database developed by Woods and Corbin 2003a).

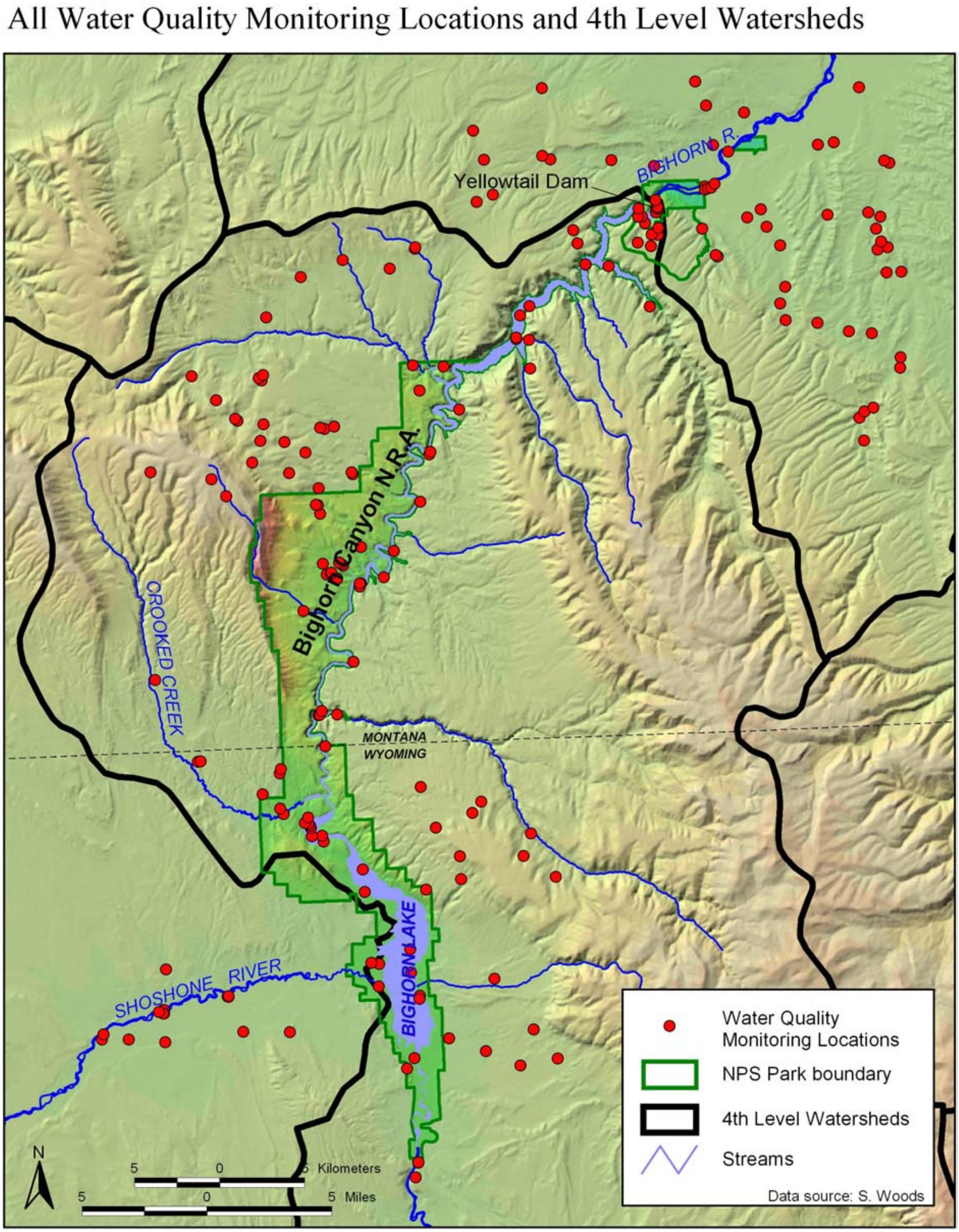


Figure 3. Historic and current water quality monitoring locations in GRTE (from database developed by Woods and Corbin 2003b).

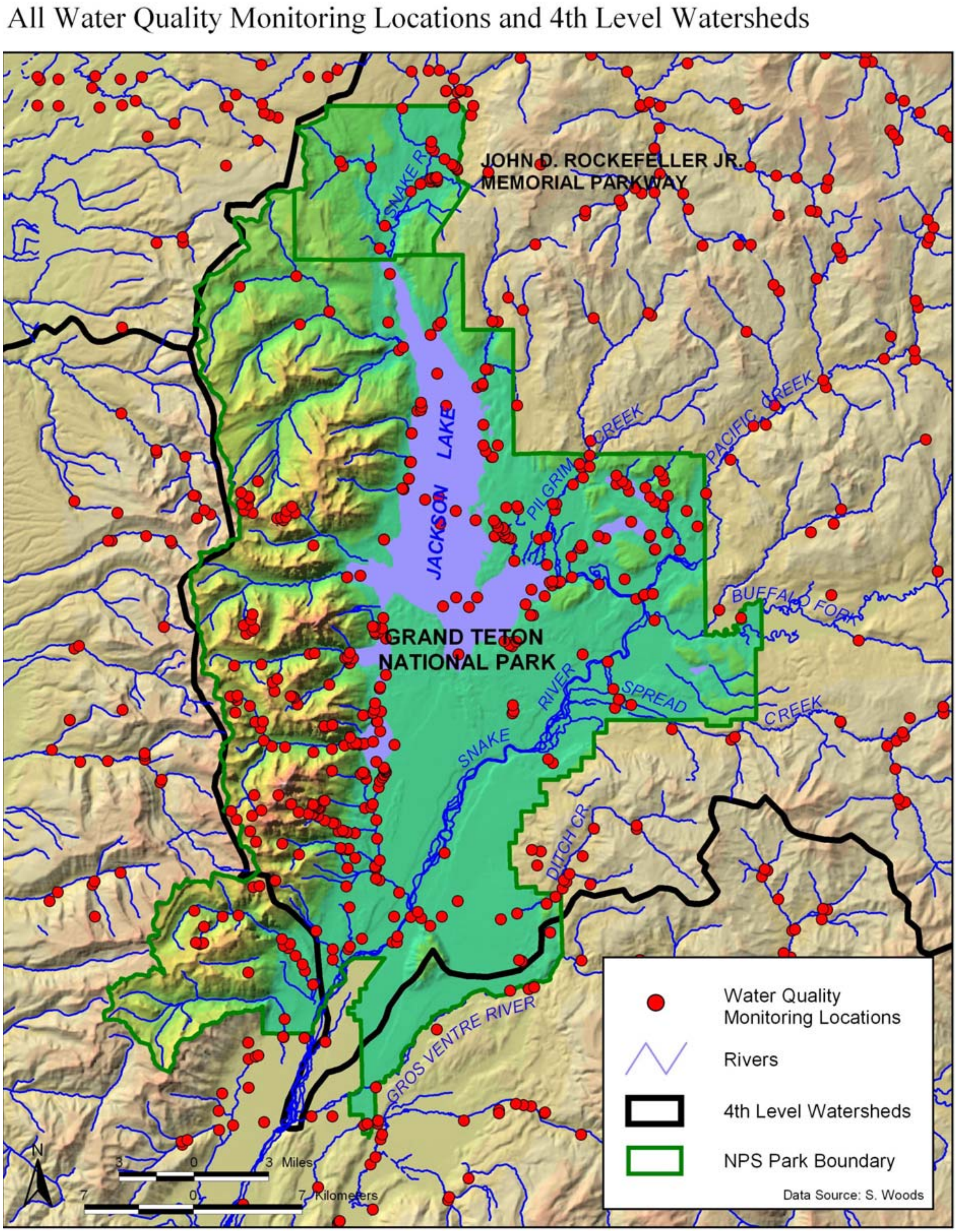
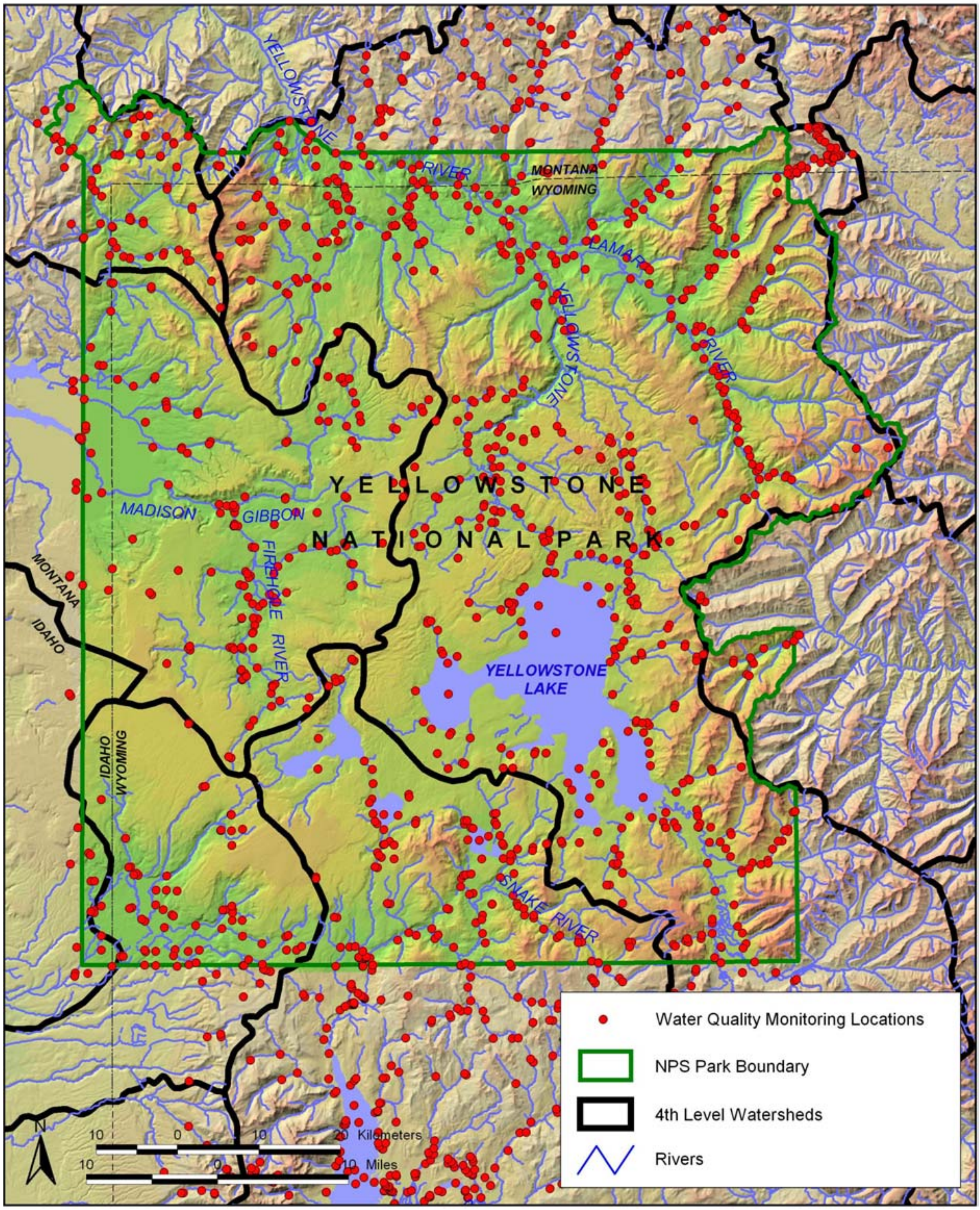


Figure 4. Historic and current water quality monitoring locations in YELL (from database developed by Woods and Corbin 2003c).

All Water Quality Monitoring Locations and 4th Level Watersheds



APPENDIX F. Location of current monitoring stations in the GRYN and table of locations and parameters monitored

Figure 5. Current water quality monitoring locations in BICA (from personal comm., Robert Swanson, USGS)

Current Water Quality Monitoring Locations and 4th Level Watersheds

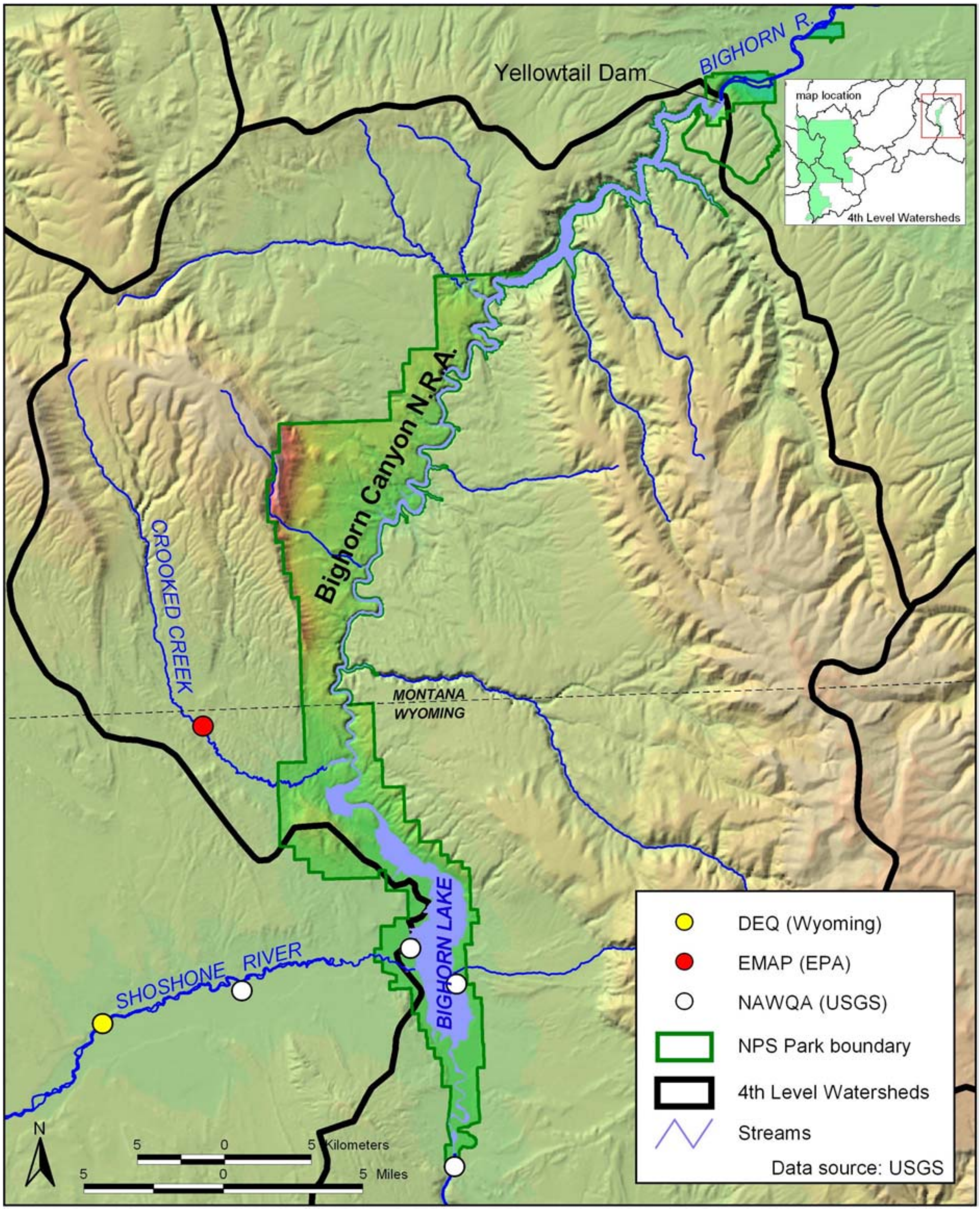


Figure 6. Current water quality monitoring locations in GRTE (from personal comm., Robert Swanson, USGS).

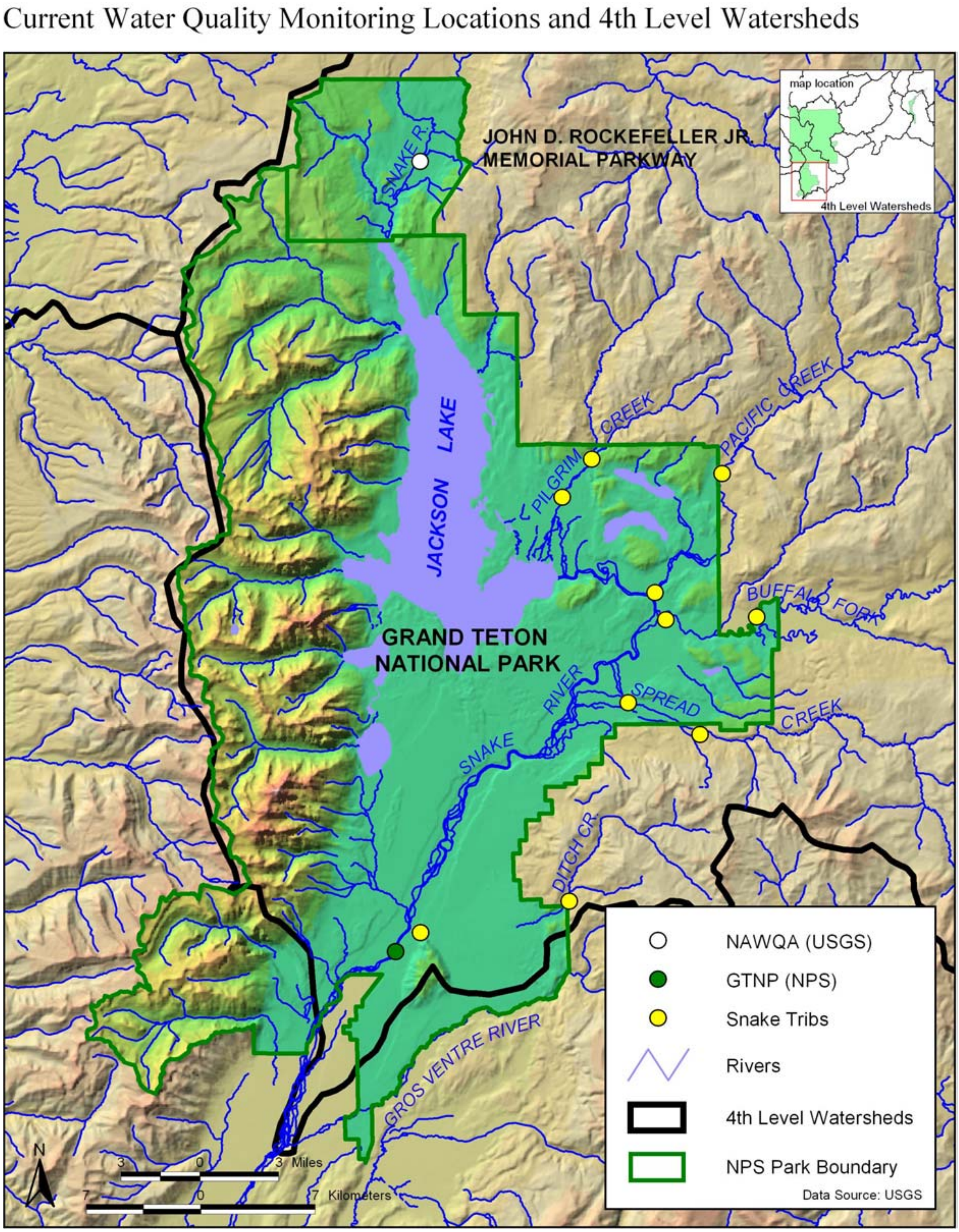


Figure 7. Current water quality monitoring locations in YELL (from personal comm., Robert Swanson, USGS).

Current Water Quality Monitoring Locations and 4th Level Watersheds

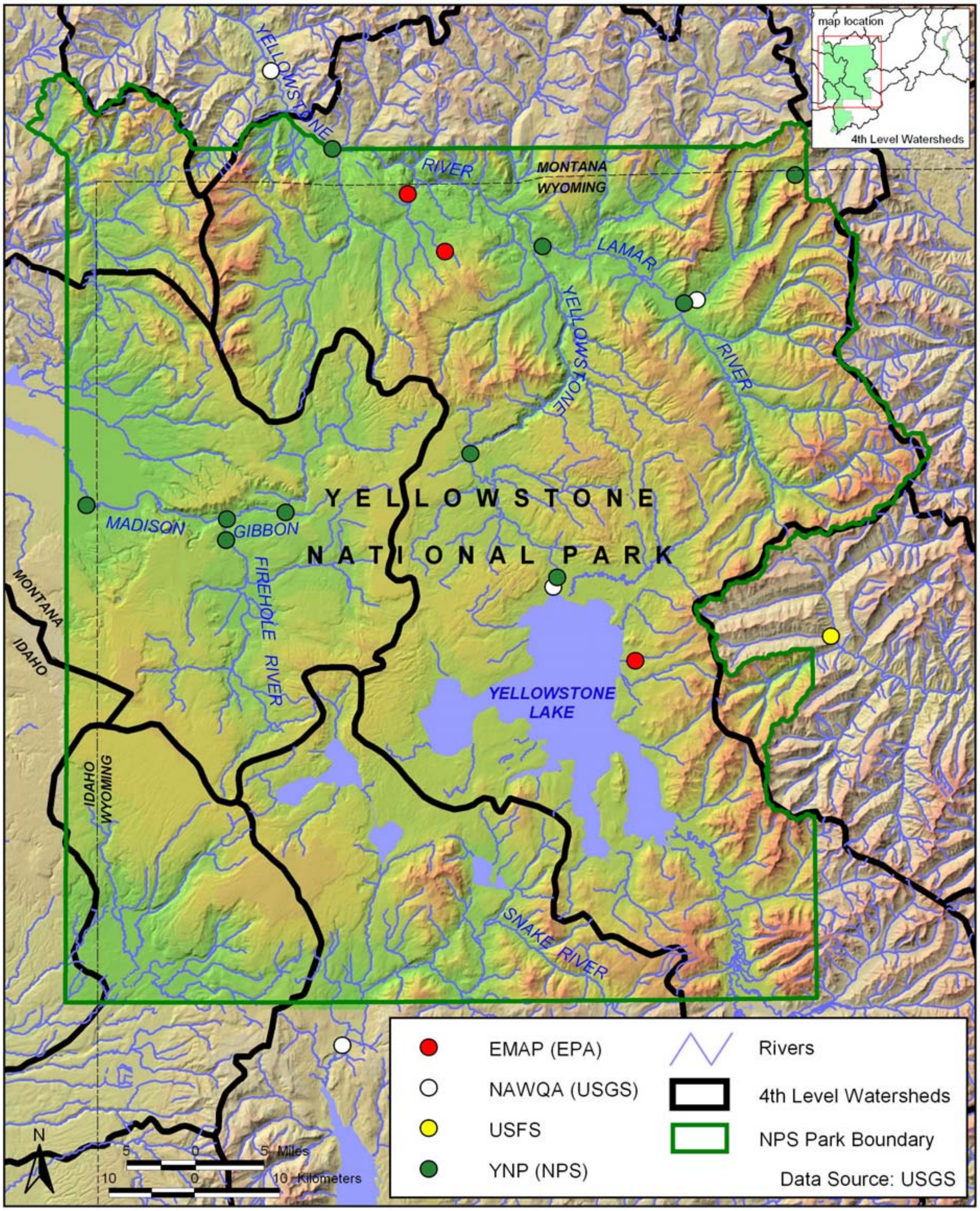


Table 8. Current GRYN water quality monitoring locations, type of data collected and frequency (personal comm., Robert Swanson, USGS).

Site ID	Site Name	Latitude/Longitude	Datum	Program	Type of data collected	Frequency	Years
06036950	Gibbon River below Canyon Creek near West Yellowstone, MT	443851/1104625	NAD 27	YNP	daily sediment	daily/summer	2000
06037100	Gibbon River at Grand Loop Bridge, at Madison Junction, YNP	443826/1105137	NAD 27	YNP	daily sediment	daily/summer	2000
06186500	Yellowstone River at lake outlet	443403/1102248	NAD 27	NAWQA	bed sediment and fish tissue -- trace elements and organic compounds	once	1998
06187915	Soda Butte Creek at Park boundary	445208/1100953	NAD 27	NAWQA	bed sediment and fish tissue -- trace elements and organic compounds	once	1998
				NAWQA	habitat, algae, invertebrates, fish community	once	1999
				NAWQA	algae, invertebrates	once	2000
				NAWQA	nutrients, major ions, trace elements, bacteria	monthly plus high flow	1999-2001
				NAWQA	trace element loading study	once	1999
06191500	Yellowstone River at Corwin Springs	450643/1104737	NAD 27	NAWQA	bed sediment and fish tissue -- trace elements and organic compounds	once	1998
				NAWQA	habitat, algae, invertebrates, fish community	once	1999
				NAWQA	algae, invertebrates	once	2000
				NAWQA	nutrients, major ions, trace elements, bacteria	monthly plus high flow	1999-2001
06279500	Bighorn River at Kane	444531/1081051	NAD 27	NAWQA	bed sediment and fish tissue -- trace elements and organic compounds	once	1998
				NAWQA	habitat, algae, invertebrates, fish community	once	1999
				NAWQA	algae, invertebrates	once	2000
				NAWQA	nutrients, major ions, pesticides, bacteria	monthly plus high flow	1999-2001
06279795	Crow Creek at mouth, near Pahaska	443048/1095822	NAD 27	USFS	nutrients, major ions	twelve/summer	2001-
				USFS	trace elements, organic carbon	six/summer	2001-
				USFS	Discharge, sediment	Daily	2001-
				USFS	Temp, pH, sp. Cond, D.O.	continuous	2001-
06285100	Shoshone River near Lovell	445020/1082600	NAD 27	DEQ	nutrients	four/year	1999-
					bacteria	four/year	2000-
06286200	Shoshone River at Kane	445131/1081952	NAD 27	NAWQA	major ions, sediment,	eleven/summer:one/summer	1999:2000
				NAWQA	nutrients, pesticides	eleven/summer	1999
				NAWQA	trace elements	four/year	1999
				NAWQA	bacteria	one/year	2000
445110108102901	Bighorn Lake at Highway 14A	445112/1081029	NAD 27	NAWQA	bed sediment and fish tissue -- trace elements and organic compounds	once	1998

Site ID	Site Name	Latitude/Longitude	Datum	Program	Type of data collected	Frequency	Years
445221108122601	Shoshone River at mouth	445221/1081226	NAD 27	NAWQA	bed sediment and fish tissue -- trace elements and organic compounds	once	1998
WWYP99-0533	Blacktail Deer C	44.98153/110.592	NAD 83	EMAP	habitat, algae, invertebrates, fish community, fish tissue	once	2000
WWYP99-0608	Unnamed trib to Blacktail Deer C	44.92105/110.5373	NAD 83	EMAP	habitat, algae, invertebrates, fish community, fish tissue	once	2001
WWYP99-0659	Crooked C	44.99132/108.35394	NAD 83	EMAP	habitat, algae, invertebrates, fish community, fish tissue	two/year	2002-2003
WWYP99-0721	Cub C	44.48984/110.26107	NAD 83	EMAP	habitat, algae, invertebrates, fish community, fish tissue	once	2003
13010065	Snake River above Jackson Lake, at Flagg Ranch	440521/1104138	NAD 27	NAWQA	nutrients, major ions, sediment concentration,organic carbon	six/year	
				GTNP	Pesticides	two/year	
				NAWQA	habitat, algae, invertebrates, fish community	once	2003
13013650	Snake River at Moose Junction Bridge	433914/1104252	NAD 27	GTNP	nutrients, major ions, sediment concentration	nine/year	
				GTNP	Organic carbon	six/year	
				GTNP	Pesticides	two/year	
435529110335101	PILGRIM CR BLW PK BNDRY, NR MORAN, GTNP, WYO	435529/1103351		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
13010450	PILGRIM CREEK NEAR MORAN, WY	435414/1103512		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
435459110275401	PACIFIC CR ABV PK BNDRY, GTNP, NR MORAN, WYO	435459/1102754		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
13011500	PACIFIC CREEK AT MORAN, WY	435104/1103059		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
13011900	BUFFALO FORK ABOVE LAVA CREEK NEAR MORAN, WY	435014/1102621		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
13012000	BUFFALO FORK NEAR MORAN, WY	435010/1103030		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002

Site ID	Site Name	Latitude/Longitude	Datum	Program	Type of data collected	Frequency	Years
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
13012490	SPREAD CREEK AT DIVERSION DAM, NEAR MORAN, WY	434622/1102859		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
13012500	SPREAD C NR MORAN WY	434726/1103214		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
13013530	DITCH C BEL S FR NR KELLY WYO	434053/1103458		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	one/year	2003
13013600	DITCH CR NR MOOSE	433952/104144		Snake Tribs	Pesticides, trace elements	one/year	2002
				Snake Tribs	majors, nutrients, Sed. Conc.	three/year	2002

APPENDIX G. Park identified water quality monitoring needs

Table 9. BICA's suggested water quality monitoring needs.

Vital Sign or Category to be monitored →	Streamflow (discharge)	Reservoir Elevation	Core Parameters (including other basic physical property values to be taken at each sampling site)	Major Ion Chemistry (may include specific minor inorganics of importance such as Mercury is to BICA)			E. Coli	Stream Sediment Transport	River invertebrate assemblages	Algal species composition and biomass	Organics (pesticides, etc; this is a category specific to BICA only)		
Waterbody/location to be sampled ↓	gage height, discharge, real time, recent, daily, monthly, annual, peaks, measurements, etc.	feet elevation	Core parameters as identified by WRD and physical property descriptors such as: site identifier, date and time of sample; parameter, hydrologic condition and event, lab, sample type, sample medium, sample purpose, sampler type and replicate codes; agency collecting and analyzing sample; number of sampling points; quality assurance data; and sample weight and volume.	Nutrients (Total nitrogen, Organic nitrogen, Ammonia, Nitrite, Nitrate, Ammonia plus organic nitrogen, Nitrite plus nitrate, Orthophosphate, Phosphorus)	Major Inorganics (major ion chemistry; Sulfate, Calcium, Magnesium, Potassium, Sodium, Sulfur, Organic carbon, Inorganic carbon, Carbon (inorganic plus organic))	Minor and Trace Inorganics (things like Aluminum, Arsenic, Barium, Beryllium, Chromium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Zinc, etc.)	May also include other pathogens and biological parameters (Total coliform, Fecal coliform, and Escherichia coli)	Sediment (Bed sediments smaller than 0.0625, 0.125, 0.25 millimeters, 0.5 millimeters,1, and 2 millimeters and occasionally include turbidity and/or Secchi depths)	Biological assemblages of invertabrates, includes taxonomic and community analysis	Composition, biomass, visual indices, floating alga mats, etc.	Organics (pesticides, etc.)	**Sampling frequency**	**Why are we monitoring?**
SHOSHONE RIVER AT MOUTH, NEAR KANE, WY Big Horn County, Wyoming Hydrologic Unit Code 10080014 Latitude 44°52'21", Longitude 108°12'26" NAD27 Drainage area 2,977 square miles Contributing drainage area 2,977 square miles Gage datum 3,650 feet above sea level NGVD29	X		X	X	X	X	X	X	X		X	quarterly plus events (six times per year)	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
BIGHORN RIVER AT KANE, WY Big Horn County, Wyoming Hydrologic Unit Code 10080010 Latitude 44°45'31", Longitude 108°10'51" NAD27 Drainage area 15,765.00 square miles Gage datum 3,660.00 feet above sea level NGVD29	X		X	X	X	X	X	X	X		X	quarterly plus events (six times per year)	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
CROOKED C NR LOVELL WY Latitude 44°57'49", Longitude 108°16'44" NAD27, Big Horn County, Wyoming , Hydrologic Unit 10080010 DRAINAGE AREA 119.00 square miles	X		X	X	X	X	X		X		X	monthly	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions

TRAIL CREEK ABV CAMPGROUND	X		X	X	X		X	X	X			monthly (bi-weekly during the summer)	understand park specific issues, and relevant to potential future management actions
TRAIL CREEK BLW CAMPGROUND	X		X	X	X		X	X	X			monthly (bi-weekly during the summer)	understand park specific issues, and relevant to potential future management actions
Bighorn River near St. Xavier, MT Hydrologic Unit Code 10080015 Latitude 45°19'00", Longitude 107°55'05" NAD27 Drainage area 19,667.00 square miles Gage datum 3,158.3 feet above sea level NGVD29	X		X	X	X	X	X	X	X		X	quarterly plus events (six times per year)	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
Layout Creek above Ranger Station	X		X	X	X		X	X	X			monthly during winter (bi-weekly during spring, summer, and fall due to cattle trailing)	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
Layout Creek below Bad Pass Trail	X		X	X	X		X	X	X			monthly during winter (bi-weekly during spring, summer, and fall due to cattle trailing)	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
Bighorn Lake at Horseshoe Bend		X	X	X	X	X	X			X	X	two times per year plus events (bi-weekly during contact recreation season)	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
Bighorn Lake at Yellowtail Dam		X	X	X	X	X	X			X	X	two times per year plus events	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
Bighorn Lake above Porcupine Creek		X	X	X	X	X	X			X	X	two times per year plus events	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
Bighorn Lake below Porcupine Creek		X	X	X	X	X	X			X	X	two times per year plus events	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
Bighorn Lake at Ok-A-Beh Marina		X	X	X	X	X	X			X	X	two times per year plus events and bi-weekly during contact recreation season	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions
Bighorn Lake at Barry's Landing		X	X	X	X	X	X			X	X	two times per year plus events and bi-weekly during contact recreation season	monitor ecosystem health, understand park specific issues, and relevant to potential future management actions

Table 10. GRTE's suggested water quality monitoring needs.

	Streamflow	Major ion chemistry (includes ANC in sensitive catchments)	River invertebrate assemblages	Algal species composition and biomass	E. coli	Reservoir elevation	Continuous water temperature	Stream sediment transport
Snake River at Flagg Ranch	X	X	X					
Snake River at Moose	X	X	X				X	
Jackson Lake		X		X		X		
Snake Tribs (east side)	X	X	X					
Snake Tribs (west side)	X				X			
High Alpine Lakes		X		X				

Table 11. YELL's suggested water quality monitoring needs.

Waterbody	Vital Sign										Frequency
Fixed Site Locations	**Discharge**	**Core Parameters**	**Turbidity**	**Secchi**	**Cations/Anions**	**Nutrients**	**Metals**	**Suspended Solids**	**Chlorophyll-a**	**Invertebrate**	
Firehole River @ mouth	X**	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Gardiner River @ mouth	X**	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Gibbon River @ mouth	X**	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Lamar River @ mouth	X**	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Madison River @ park boundary	X**	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Pelican Creek @ mouth	X	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Snake River @ park boundary	X**	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Soda Butte Creek @ park boundary	X**	X	X		X	X	X	X	X	X	Bi-weekly Jan-Dec
Soda Butte Creek @ mouth	X**	X	X		X	X	X	X	X	X	Bi-weekly Jan-Dec
Yellowstone River @ Corwin Springs	X**	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Yellowstone River @ Artist Point	X	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Yellowstone River @ Fishing Bridge	X**	X	X		X	X		X	X	X	Bi-weekly Jan-Dec
Yellowstone Lake @ West Thumb		X	X	X	X	X		X	X	X	Bi-Weekly May-Oct
Yellowstone Lake @ South Arm		X	X	X	X	X		X	X	X	Bi-Weekly May-Oct
Yellowstone Lake @ Southeast Arm		X	X	X	X	X		X	X	X	Bi-Weekly May-Oct
Yellowstone Lake @ Stevenson Isld.		X	X	X	X	X		X	X	X	Bi-Weekly May-Oct

APPENDIX H. Discussion of state water quality standards

Wyoming Standards

The State of Wyoming has four major surface water classes which include seven beneficial uses: outstanding waters; fisheries and drinking water; aquatic life other than fish; and agriculture, industry, recreation and wildlife. Four degrees of support of the designated use are used in Wyoming. These are Full Support (no impairment indicated by all data types); Fully Supporting but Threatened (no impairment indicated by all data types but with declining trend in water quality over time); Partial support (impairment indicated by one or more data types); Nonsupport (impairment indicated by all data types).

State (WY) Standard for Temperature
Chapter 1, Wyoming Water Quality Rules and Regulations, (1999), surface water quality standards for class 1 and 2 waters prohibit temperature increases which change natural water temperatures to levels which are deemed harmful to existing aquatic life. In addition, the water quality standards prohibit activities which cause temperature changes in excess of 2°F (1.1°C) from ambient water temperatures for class 1 and 2 waters that are cold water fisheries. The temperature standard prohibits activities which cause temperature changes in excess of 4°F (2.2°C) from ambient water temperatures for class 3 waters and class 1 and 2 waters which are warm water game fisheries. No artificially induced temperature change over spawning beds is allowed in any class 1, 2, or 3 water. High summer water temperatures are critical to trout, which prefer water temperatures of 13 deg. C and do best when water remains continuously below 21 deg C (WY DEQ, 1999).

State (WY) Standard for pH
The range of acceptable pH values for Wyoming surface waters is 6.5 to 9.0

State (WY) Standard for Fecal Coliform
In order to be fully supporting for recreational water use, Wyoming water quality rules and regulations state that during the entire year, fecal coliform concentrations shall not exceed a geometric mean of 200 organisms per 100 milliliters (based on a minimum of not less than 5 samples obtained during separate 24 hour periods for any 30 day period), nor shall the geometric mean of 3 separate samples collected within a 24 hour period exceed 400 organisms per 100 milliliters in any Wyoming surface water.

State (WY) Standard for Specific Conductivity
Surface water standards for conductivity are not established in Wyoming because these parameters generally pose no threat to surface water supplies. However, water with a high specific conductance (>6,900 μmhos/cm) has been reported to negatively affect aquatic organisms (WY DEQ, 1999).

State (WY) Standard for Nitrogen
The water quality standard for nitrate as nitrogen (N) and for nitrate plus nitrite as nitrogen (N) is 10,000μg/l (10 ppm).

State (WY and MT) Standard for Dissolved Oxygen (DO)

Minimum dissolved oxygen (mg/l) criteria for cold water fisheries, early life stages are: a 7 day mean water column concentration of 9.5 (recommended to achieve the required intergravel dissolved oxygen concentration of 6.5) and a 7 day mean concentration of 6.5 for species that have early life stages exposed directly to the water column; and a 1 day minimum (instantaneous concentration to be achieved at all times) concentration of 8.0 (recommended to achieve the required intergravel dissolved oxygen concentration of 5.0) and a 1 day mean minimum concentration of 5.0 for species that have early life stages exposed directly to the water column. The criteria for other life stages are: 30 day mean of 6.5; 7 day mean minimum of 5.0; and a 1 day minimum of 4.0.
Trout and other coldwater fish require a minimum of 6 to 7 mg/l dissolved oxygen (WY DEQ, 1999).

Montana Standards
Montana surface waters were classified based on a review of exisiting water quality information(evidence) from the following three broad categories:
Physical/habitat – includes qualitative and/or quantitative riparian and aquatic vegetation information, and hydrogeomorphic characteristics and functions. For example, data may include stream reach habitat surveys with photos to document impairments, and physical measurements of the stream channel, such as pebble counts and channel cross sections.
Biology – includes chlorophyll *a* data; and aquatic biological assemblage data relating to fish, macroinvertebrates, and algae; and wildlife community characteristics. Measurements often include population estimates, biomass, number and relative abundance of sensitive or pollution-tolerant species, diversity, and distribution.
Chemistry/toxicity – includes bioassays; temperature and total suspended sediment data; and chemistry data such as concentrations of toxicants, nutrients, and dissolved oxygen.

The State of Montana has six beneficial use categories for their surface water classification: agriculture; aquatic life support; cold water fishery – trout; drinking water supply; industrial; and primary contact (recreation). The degree of support of the beneficial use is then classified as: fully, threatened, partial, not supporting or not assessed.

According to Montana standards, "partially supporting" requires two or more data categories indicating moderate impairment or one data category indicating severe impairment (i.e. physical/habitat biology or chemistry/toxicity) with the remaining data categories indicating that the waterbody is unimpaired or least impaired; OR two biological assemblages indicating moderate impairment; or one biological assemblage indicating less than 50% of reference condition.

Specific surface water quality standards protect the beneficial water uses set forth in the water-use descriptions. The 303(d) listed waters in the state of Montana have all been classified as B-1, and are to be maintained suitable for drinking, culinary and food processing purposes, after conventional treatment; bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Data showing current human-caused impairments for aquatic life uses normally constitute overwhelming evidence when they document:

• Any exceedence of an acute aquatic life standard.
• A 250% exceedence of a chronic aquatic life standard, even if there is only one credible data point.
• Any exceedence of an aquatic life standard based on sufficient data to calculate a geometric mean. "Geometric mean" means the value obtained by taking the Nth root of the product of the measured values where zero values for measured values are taken to be the detection limit.
• Any 50% exceedence of a narrative standard (e.g. sediment levels in an impaired stream reach are determined to be 50% greater than sediment levels of an appropriate reference site).
• Any activities that negatively impact habitat by more than 50% (e.g. less than 50% of a stream corridor has adequate riparian habitat when compared to potential or reference condition).
• Any activities that negatively impact biological communities by more than 50% (e.g. a fish population reduced to less than 50% of its potential due to sedimentation; or macroinvertebrate communities less than 50% of those in reference waters).

State (MT) standard for pH
Variation of hydrogen ion concentration (pH) within the range of 6.5 to 8.5 must be less than 0.5 pH unit. Natural pH outside this range must be maintained without change. Natural pH above 7.0 must be maintained above 7.0.

State (MT) Standard for Temperature
1ºF maximum increase above naturally occurring water temperature is allowed within the range of 32ºF to 66ºF; within the naturally occurring range of 66ºF to 66.5ºF, no discharge is allowed which will cause the water temperature to exceed 67ºF; and where the naturally occurring water temperature is 66.5ºF or greater, the maximum allowable increase in water temperature is 0.5ºF. A 2ºF per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55ºF. A 2ºF maximum decrease below naturally occurring water temperature is allowed within the range of 55ºF to 32ºF. This applies to all waters in the state classified B-1 except for Prickly Pear Creek from McClellan Creek to the Montana Highway No. 433 crossing where a 2ºF maximum increase above naturally occurring water temperature is allowed within the range of 32ºF to 65ºF; within the naturally occurring range of 65ºF to 66.5ºF, no discharge is allowed which will cause the water temperature to exceed 67ºF; and where the naturally occurring water temperature is 66.5ºF or greater, the maximum allowable increase in water temperature is 0.5ºF.

State (MT) Standard for Specific Conductivity
Montana has no standard for Specific Conductivity, however, agricultural supply water are considered to be unimparied if conductivity values <1500 µ (Agriculture Supply Beneficial Use Support Decision Tables, Appendix A, Water Quality Assessment Process and Methods).

APPENDIX I. Conceptual models (narrative) from Jean et al. 2003.

AQUATIC ECOSYSTEM NARRATIVE CONCEPTUALMODEL—BOB HALL

The GYRN contains a diverse group of lakes , both natural and human-made. There are numerous glacier-carved lakes in high alpine areas of the Teton Range, and several large lakes formed from tectonic processes. Bighorn Canyon contains a large impoundment, and the top 8 m of Jackson lake is regulated by a dam at its outlet. The large lakes contain substantial biological and economic resources. For example, Yellowstone lake has the largest population of Yellowstone cutthroat trout (*Onchoryncus clarki bouveri*) (Gresswell and Varley 1988). These lakes are used extensively for recreation, such as boating and fishing. Bighorn and Jackson lake are used for water storage.

River ecosystems are equally diverse in the GYRN. Rivers ranges from large lake outlets (e.g. Snake and Yellowstone rivers, to many high-mountain streams, and geothermally influenced rivers in the Madison drainage and South Boundary area of YNP. High variation in groundwater source, parent material, and topography lead to high variation in the types of streams within GYRN. In terms of ecosystems functions such as whole stream metabolism and nitrogen processing, streams within GTNP are more variable than 11 streams within different biomes ranging from the tropics to Alaska (Hall and Tank 2003). In this narrative I will only consider the aquatic part of rivers as the riparian section is covered elsewhere, though stressors to streams and lakes can come from habitat damage to the riparian zone.

Drivers.

Lakes are formed by exogenous processes (glacial scour, plate movement, dams, differential cooling of lava in the case of Yellowstone lake), and these processes shape the morphometry of the lake which, in turn will determine most aspects of its function. Climate plays a large role in temperature, hydrology and mixing regime of lakes. Human activities can affect lakes by altering hydrology, climate, nutrient load and biotic assemblages. Drivers for rivers are similar to those for lakes, except with the fundamental difference that rivers morphology is a function of the hydrology (driven by climate) of the river and geology of the drainage basin as channel structure changes through time. Changes in climate will affect hydrology and temperature of rivers, and humans can strongly impact rivers by altering hydrology, geomorphology and biotic assemblages.

Temperature: Climate change may be an important stress to Yellowstone ecosystems over the long term. Lakes can be used as bellwethers of climate changes and will likely be affected by global climate change. Long term records of ice-out on lakes suggest warming of lakes (Likens 2000, Magnuson 2000) and effects of climate change in the watershed, e.g. increased fire frequency, may alter lake dynamics (Schindler et al. 1996). Increasing temperature will affect biota of rivers directly, e.g. by limiting distribution of coldwater species (Rahel et al. 1996). Alternatively increased temperature could provide for faster growth rates of fish in rivers and lakes, including invasive lake trout (Hill and Magnuson 1990), which may change predator-prey dynamics in lakes.

Water level and river hydrology: Lakes that are hydrologically managed (e.g. Jackson Lake, Bighorn lake) will have fluctuating water levels that can potentially lake food webs and ecosystem function. Lakes are linked to their shoreline and receive a fraction of their energy inputs from allochthonous inputs, coarse woody debris which provides habitat, and may control terrestrial predator interactions (Schindler and Scheuerell 2002). Changing water level may decrease allochthonous inputs and may limit access of the lake by terrestrial predators (e.g. otters). Rivers can by altered hydrologically from dam operations (e.g. Snake river), which can alter biotic assemblages (Stanford and Ward 1989). Water removal for irrigation can reduce instream flows and flood peaks in the summer, (e.g. Gros Ventre River, Bighorn River, Shoshone River, Spread Creek). Additionally climate change may alter stream hydrology (Poff 2002) which will affect all aspects of river ecosystem function (Meyer et al. 2000, Firth and Fisher 1995) ranging from food web interactions (Power et al. 1995) to nutrient cycling.

Sedimentation and geomorphology. An important stress, covered in the riparian narrative.

Solute concentrations. Solutes include all dissolved solids in water, which strongly affect lake ecosystems. Drought, and fire change cation import to lakes (e.g. Schindler et al. 1996) High mountain lakes may be subject to acidification if they are poorly buffered; however western mountains tend to have lower acid inputs than Northeastern US mountains. In the Snowy Range, SE Wyoming, despite low acid-neutralizing capacity of lakes, acidification is not yet evident because pH of precipitation is higher than that in the Eastern US. (Reuss et al. 1995)

Nutrient loading. Eutrophication from excess nutrients is a pervasive stress on many lakes and rivers in the US by increasing primary production, changing biotic assemblages and lowering water clarity; estimating the effects of this eutrophication has a long history (Smith 1998). Local development and atmospheric deposition can cause nutrient loading even in large mountain lakes such as Lake Tahoe. For example, increased N loading to Lake Tahoe has increased primary production and decreased water clarity (Goldman 1988). The effect of excess nutrients to rivers is much less well known; experimentally increased P loading to a tundra river increased primary productivity, moss biomass and secondary production (Peterson et al. 1993). Phosphorus is often considered the limiting nutrient for lakes and streams, however it is now recognized that nitrogen often limits production as well (Elser et al. 1990). Nitrogen is most likely to be the limiting nutrient for most lake ecosystems within the GYRN; almost all streams in GTNP are N limited (J. L. Tank and R. O. Hall unpublished data). Planktonic algae responded greatly to N additions in experimental bioassays showing that N was primarily limiting in Yellowstone and Jackson lakes (Interlandi and Kilham 1998), thus we suggest that N will be a more important pollutant than P in the GYRN.

In the West, there are areas with high N loading from atmospheric deposition, particularly near cities and areas downwind from power plants or intensive agriculture Fenn et al. 2003b). Loch Vale in Rocky Mountain National Park receives 3-5 kg N ha-1 y-1, (Baron et al. 2000), and this N has been implicated in changing the phytoplankton assemblages in these lakes (Wolfe et al. 2001). Lakes in the GRYN are fairly low-nutrient (Interlandi et al. 1999) thus they are likely to respond to small increases in nutrients similarly to Tahoe. Indeed, eastern Idaho and the Teton range are projected to have high rates of N deposition (Fenn et al. 2003b). Primary sources would most likely be atmospheric deposition or from local inputs from towns and settlements within the parks. High mountain lakes could be most susceptible because they can receive high N loads from atmospheric deposition, and many lakes in the west have high nitrate concentrations (Fenn et al. 2003a), although there are almost no data represented in their paper from western Wyoming, despite have large high elevation areas with crystalline bedrock that is potentially susceptible to increased nitrate loading.. Although N deposition rates are low in areas far from cities (e.g. west slope of Colorado Rockies, Baron et al. 2000), deposition could increase as NOx emissions and local development increases (see Vitousek et al. 1997).

Rivers upstream of Bighorn canyon run through agricultural areas an have elevated nutrient loads ands N and P (Water Resources Division, National Park Service1998), which might contribute to the eutrophic nature of Bighorn Lake (Lee and Jones 1981).

Exotic species: Exotic species are one of the most pervasive environmental problems in the US and the GYRN has received some well-publicized invasions that can potentially alter aquatic ecosystems. Lake trout (Savelinus namaycush) have invaded Yellowstone lake and may lower native cutthroat trout populations (Stapp and Hayward 2002a, Ruzyicki et al. 2003) and may extend to predators outside the lake (Stapp and Hayward 2002b). Lake trout can consume 14% of juvenile cutthroat trout (Onchorhyncus clarki) populations per year, even when numbers are controlled by gill-netting.

Whirling disease has also invaded rivers in Yellowstone which may impact cutthroat trout populations (Ruzyicki et al. 2003). New Zealand mud snails (Potamopyrgus antipodarum) have invaded many rivers in the GYRN and are likely having severe impacts. In Polecat Creek, New Zealand mud snails constitute 90% of invertebrate biomass, and represent the largest fluxes in the nitrogen cycle (Hall et al. in review). Secondary production of mud snails in Polecat Creek is one of the highest rates ever recorded for an aquatic invertebrate (Hall et al. in preparation). It is not likely that these will be the last invasions, as Simberloff and Von Holle (1999) suggest that invasions beget more invasions; evidence in the Great Lakes suggests that this hypothesis is true, as the invasion rate is increasing non-linearly. (Ricciardi 2001).

Potential Indicators

Indicators can be integrative assessments of biological condition (Karr 1981, 1999) (i.e. looking for the effect). Measuring biotic condition is important because it represent the impact that managers and visitors to the parks care about: Are there fish to catch? Are there wildlife to observe? Is the lake clear? Also, biota can indicate multiple stressor and often provide a better information on change than hard-to measure-stressors (such as episodic pollution events (Karr 1999). Alternatively we can examine the stressor itself. Measuring changes in the stressor (if possible) is important for 2 reasons: One is that it may be possible to detect change in the stressor long before there is an impact to ecological processes. For example, N inputs or temperature may increase before the biotic assemblage responds. Invasion of an animal to a new ecosystem can be detected more easily than the impact to native populations or ecosystem processes. The other reason is that measuring the stressor may help to understand causes of observed biological changes. If lake clarity decreases concomitantly with nutrient loading, then increased nutrients are a strong causal hypothesis for this biological change.

1. Indicator: Nitrogen inputs

Justification. Atmospheric nitrogen input is a stressor that, if high enough, could increase primary production in lakes and streams. Given that most N loading to Yellsostone and Teton Parks is via atmospheric inputs (as opposed to urbanization or agriculture), measurement of nitrogen concentrations in precipitation may detect early changes to these inputs. There are few NADP sites in the GYRN and the one in Yellowstone is a low elevation where concentration and of nitrate and volume of precipitation are expected to be low. There are few high-elevation sites for N deposition in the intermountain west (Fenn et al. 2003b), thus inputs on N and changes of those inputs are relatively unknown for the GYRN. Examples of specific measures: Annual wet and dry deposition of N at a few high and mid elevation sites within the GYRN.

2. Indicator: Nitrogen concentrations in aquatic ecosystems

Justification.: Atmospheric nitrogen input is a stressor that, if high enough, could increase primary production in lakes and streams. High alpine watershed lose most of their nitrogen during snowmelt (e. g. Reuss et al. 1995), and losses are proportional to inputs (Williams et al. 1996), despite processing of N in the shallow soils. Stream monitoring can detect long-term trends in deposition (Likens et al. 1996), and may provide a means to detect watershed-level response to N additions (Williams et al. 1996). Examples of specific measures: Temporal sampling of stream water N throughout the year in Teton Range streams, Bighorn River and Lake and possibly some Yellowstone rivers. Surveys of N concentrations in lakes.

3. Indicator: Water Temperature

Justification. Global climate change may increase temperatures of lakes and streams which may alter animal habitat and interactions. Additionally, geologic change (e.g earthquake in Firehole River basin) may alter groundwater inputs with corresponding temperature changes in rivers. Measurement of temperature may be able to detect these changes which can be linked to any biological changes.

Examples of specific measures: Hourly recording of temperature in lake epilimnia and rivers via inexpensive recording thermometers. Ice out dates for major lakes.

4. Indicator: Surface hydrology
Justification: Hydrology of lakes and rivers in the GYRN can change from direct human modification (e.g. impoundments, water abstraction) or via changes in climate (Meyer et al. 1999). This monitoring is already occurring for several of the rivers in GYRN, e.g. Snake, Bighorn, Madison, Yellowstone, and 2 of the lakes, Jackson and Bighorn. Examples of specific measures Lake water level, and large river discharge.

5. Indicator, River morphology and habitat assessment (as specified in riparian narrative)

6. Indicator. Algal species composition and biomass
Justification. Increased nutrients of changes to the food web (e.g. Carpenter et al. 1985) may change algal biomass, water clarity and species composition. Research in Yellowstone Lakes has shown that diatom species compositions predictably respond to slight changes nutrients according to their physiology (Interlandi et al. 1999), and these changes in assemblages may be sensitive indicators to nutrient inputs and associated climate change (Kilham et al. 1996). Algal species in high-elevation lakes can also signal changes in nutrient concentrations (Wolfe et al. 2001).
Specific measures: Chlorophyll a concentrations of algae in lakes. Secchi disk measurements (a measure of water clarity). Algal (mostly diatoms and some cyanobacteria) assemblage structure.

7. Indicator: Cutthroat trout responses to exotic predators.
Justification. Exotic lake trout and whirling disease can potentially lower densities of native Yellowstone cutthroat trout in Yellowstone lake; these effects may cascade to streams and predators outside of the lake (Stapp and Hayward 2002).
Specific measures. Long-term quantification of Yellowstone cutthroat trout density, age structure, spawning and recruitment in Yellowstone lake and its tributaries.

8. Indicator: River invertebrate assemblages.
Justification. Stream invertebrate assemblages may change in response to exotic species, sedimentation, nutrient load or predator population change. Stream invertebrates are often used as measures of water quality (Karr 1999) and is the current approach used by the state of Wyoming for water quality analyses (King 1993). They are sensitive indicators of change and they can integrate physical stressors that might otherwise be difficult to measure, and these changes can relate to changes in ecosystem function (Wallace et al. 1996). There are several approaches to using invertebrates to measure water quality; two current methods either develop a set of additive metrics (Kerans and Karr 1994), a local examples is Wyoming index of biotic integrity (WYIBI) (Stribling), Another method uses multivariate approaches to estimate predicted invertebrate assemblages which can be compared to measured assemblage structure. e.g. Hawkins et al. (2000). Long term monitoring of invertebrates may be able to detect change in response to exotic mud snails, and new, unforeseen invasions
Specific measures: Invertebrate assemblage structure, following approaches of current bioassessment methods.

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RIPARIAN/RIVERINE ECOSYSTEM NARRATIVE CONCEPTUALMODEL—DUNCAN PATTEN

INTRODUCTION

Riverine systems often include terrestrial habitat: riparian ecosystems, stream-edge wetlands and nearly-barren sediment deposits; and aquatic habitats. This discussion of riverine systems is limited to the terrestrial ecosystems. Riparian and edge-wetlands are grouped as riparian ecosystems. Riparian ecosystems, the transition from stream to upland, occupy a very small part of the landscape, often less than 1 %, and yet play an important role in stream dynamics, wildlife ecology, and biodiversity . (Naiman et al., 1993; Naiman and Decamps, 1997; Patten, 1998). In most cases riparian ecosystems occur on alluvial sediment deposits where the hydrological connection between river and alluvial groundwater supplement water available from precipitation (Gregory et al., 1991). Riparian ecosystems offer many ecological services and functions. These services and functions are closely related to the structure, composition and abundance of the riparian vegetation and its location within the landscape. Riparian ecosystems not only influence hydrologic and geomorphic processes, but are driven by these processes as well. This synergistic relationship between riparian vegetation and hydrogeomorphic phenomena complicates the understanding of riparian response to human activities. One important function of riparian systems is that of habitat for a wide variety of organisms. In semi-arid regions over 75% of animals species use riparian ecosystems for all or part of their life cycle (Brinson et al. 1981; Kondolf et al. 1996). Because of close affinity with various characteristics of riparian ecosystems, avian community composition often is used as a surrogate for condition of riparian systems (Anderson et al. 1983; Hunter et al. 1987).

The occurrence of most riparian communities in the Greater Yellowstone Network (GRYN) parks results from recruitment and survival of obligate riparian plant species in response to seasonal hydrological events, variation in groundwater depth, and availability of favorable fluvial geomorphic surfaces. For example, most cottonwood species recruit along streams on bare moist surfaces during the declining limb of spring high flows (Friedman et al., 1995; Scott et al., 1997; Stromberg et al., 1997). Willow species may follow a similar pattern but tend to spread clonally. Survival of these woody riparian species is dependent on maintenance of a high alluvial water table and avoidance of scour events such as floods and ice flows. Mortality, or inability to survive following recruitment, may result from a water table lowered below those tolerated by young or maturing plants (Rood and Mahoney, 1995). Other factors, especially those human controlled, also play a role in riparian decline throughout the West.

LANDSCAPE DIVERSITY

The parks represented in the GRYN (i.e., Yellowstone, Grand Teton and Big Horn) have heterogeneous landscapes ranging from mountains to broad valleys and deep canyons. Consequently, streams and rivers flowing from the mountains transect a diverse geomorphology that creates steep gradients through shallow-bedrock narrow valleys as well as low-gradient, broad valleys with deep alluvial. Throughout this region, variability in valley morphology directly influences the extent and type of riparian communities (Patten, 1998). Streams flowing through broad valleys with low gradients may be lined by woody and/or herbaceous riparian vegetation. If the water table is shallow, wetland herbaceous plants (e.g., sedges and wetland grasses) may extend for some distance from the river creating fens in some areas. These wetland areas often are devoid of woody species because the herbaceous cover may prevent establishment of willows, cottonwoods or other woody plants. Willows (*Salix* spp.) and sometimes cottonwoods (*Populus* spp.) may occur near the stream where floods enhance their recruitment. Once established, these species may spread asexually and expand within the floodplain often occurring away from the stream as it migrates across the floodplain. Steep gradient mountain streams may have riparian communities of mixed willows and conifers but cottonwoods may occur on suitable sites at lower elevations. Other woody species such as dogwood (*Cornus* spp.) and alder (*Alnus* spp.) also occur along these higher gradient streams. Elevational differences also may influence riparian composition and structure. High elevation streams may not support large woody species such as cottonwood for physiological reasons. Alpine streams only support wetland herbaceous species or, occasionally, dwarf willows. Shrub willows and alders may be common along upper elevation streams sometimes mixed with stream-side conifer communities. With decreasing elevation, low stature riparian woody vegetation gives way to, or mixes with deciduous tree species. The gradient in the northern Rockies and represented in some of the GRYN parks goes from cottonwood/willow forests at lower elevations through alder/willow communities to spruce/aspen communities into alpine wetlands.

COMMON FEATURES
Structural similarities of riparian communities occur across the GRYN because they are related to successional dynamics which are driven by common fluvial-geomorphic processes. For example, point-bars, channel margin, and island deposits provide exposed sediment that supports young riparian plants along meandering and braided rivers throughout the region. Also, sediment accumulation on terraces accompanies aging of riparian vegetation and establishment of later successional species. Cottonwood species found along streams from different regions have been shown to have similar recruitment requirements (Bradley and Smith, 1986; Scott et al., 1996, 1997; Shafroth et al., 1995; Stromberg et al., 1997; Auble and Scott, 1998; Rood and Kalischuk, 1998; Shafroth et al., 1998). For example, recruitment of cottonwood and associated riparian species is most often tied to hydrological events (i.e., high flows) occurring during the period of seed dispersal. The timing and cause of these events may differ throughout the region, but early succession woody riparian species (e.g., cottonwood and willow) respond the same way to high flow, recruiting new seedlings on the receding limb of the high flow event. The year of recruitment may be delayed along GRYN rivers because snow melt floods may extend beyond the seed dispersal period, and recruitment occurs during high flows in succeeding years. Other species, for example, shrubby cinquefoil (*Potentilla fruticosa*) and water birch (*Betula glandulosa*) are also found in the riparian zone responding to other factors such as very moist soil or snow bank accumulation.
Patterns of riparian communities along elevation gradients and geomorphic gradients are similar throughout most of the GRYN. This region is arid to semi-arid thus availability of water and similarity of riparian vegetation structure allow ready transfer of information developed in one area to another.

DRIVERS OR FORCING FUNCTIONS OF RIPARIAN SYSTEMS
Hydrological factors controlling riparian processes may be quite different between the mountainous, headwater parks of Yellowstone and Grand Teton, and Big Horn Canyon NRA. Snow and ice may play a predominant role in the Yellowstone and Grand Teton while storm events on the arid landscape of Big Horn may be the primary hydrological driver. Snowmelt in the headwater parks creates a reliable hydrographic peak while erratic storms and controlled mainstem flows produce uncertain hydrographs in Big Horn. Recruitment of many riparian species is triggered by or coincides with the spring snowmelt peak which occurs in May to June (Scott et al., 1993). However, the peak may extend beyond seed dispersal causing recruitment to be delayed by a year if peak flows of the succeeding year are sufficiently high. If insufficient, recruitment may be delayed further. Heavy local storms may have greater impacts on stream flows in Big Horn than Yellowstone or Grand Teton. Less vegetative cover at Big Horn may result in flash floods in mountainous low order streams.
Recruitment of spring seed-dispersal species such as cottonwood and willow is usually most successful when high spring flows that trigger riparian recruitment are followed by a relatively dry summer, and/or absence of large floods during the next year or two (Stromberg et al., 1991). Predicting future stream flows might allow projection of changes in riparian vegetation (Auble et al. 1994 Non-native species such as tamarisk (*Tamarix ramosissima*), Russian olive (*Elaeagnus angustifolia*), and many noxious weeds disperse seeds over long periods and thus take advantage of summer storms (Stromberg, 1998).

Riparian ecosystems of GRYN region may occasionally be scoured by flash floods but some are regularly affected by ice formation. Ice forms on the surface of rivers in the northern Rockies during extreme cold periods. During ice drives, ice may be elevated and scours the bank often well above levels of spring floods (Smith, 1980). Ice scour damages existing trees, removes riparian vegetation, forms new channels and controls the elevation of successful riparian recruitment (Johnson, 1994; Scott et al., 1997).

Geomorphic influences in the GRYN region may effect how successful recruitment might be for riparian species. Many riparian species require bare moist soil for recruitment (Stromberg et al., 1991; Scott et al., 1996). Many rivers of the north Rockies have gravel- or cobble-lined channels; however, fine sediment in these rivers may be held in overbank ice in winter and deposited in spring where riparian recruitment may occur. Fine sediments also are deposited within the interstices on the cobble and gravel bars.

River geomorphology, especially on smaller streams, is often controlled or altered by beaver activity (Naiman et al. 1986). Relatively permanent beaver dam structures collect sediment, altering sediment delivery downstream, and elevate local groundwater, enhancing growth and survival of most riparian species (Johnston and Naiman 1987). When beaver dam sites are active, beavers may alter the surrounding woody vegetation, harvesting and felling stream-side trees and shrubs (Hall 1960). Eventual abandonment of beaver dam sites results in floodplains covered in fine sediments and a vegetational successional process that leads towards the vegetation that occurred prior to beaver arrival.

ENVIRONMENTAL STRESSORS

Hydrological Stressors. Factors that have created and maintained riparian systems within the GRYN parks are changing. Most changes are tied to water and channel management, land use, ungulate management, and introduction of non-native species. Throughout the region, rivers have been managed to produce water for irrigation, generate hydroelectric power, and for flood control. This is especially true in Grand Teton and Big Horn parks. In Grand Teton NP the Snake River is dammed at Jackson Lake, retaining irrigation water to be used during the growing season downstream in Idaho. Short reaches of the Snake River channel are also stabilized within GTNP.

In BICA, the Big Horn River is dammed both upstream of the park and within the park. Dams and their impoundments have greatly altered downstream ecosystems (Ligon et al., 1995; Dynesius and Nilsson 1994; Collier, et al., 1996; Shafroth, et al. 2002). They impound spring floods that normally would scour channels, deposit sediment, and produce riparian vegetation along the high water zone (e.g., Johnson, 1991). Dam releases to satisfy downstream water uses, exemplified by operation of Buffalo Bill and Boysen dams upstream of BICA and the Jackson Lake dam, often do not coincide with normal high flow periods for the river, eliminating recruitment enhancing high flows and often producing scouring summer flows (Fenner et al., 1985; Rood and Mahoney, 1990, 1995; Johnson, 1992; Dominick and O=Neill, 1998; Mahoney and Rood, 1998). Reduction of peak flows though may result in widespread narrowing of channels resulting in riparian vegetation establishment in areas that once were active channels (Johnson, 1994, 1998; Friedman et al., 1996, 1997, 1998; Shafroth et al., 1998). Even when dams allow normal flows for recruitment and maintenance of riparian species, the river below the dam may carry little sediment, material important for creation of recruitment sites (Scott et al., 1997).

Stream diversion for irrigated agriculture may reduce surface flows or effect local floodplain vegetation. Several irrigation take out channels on tributaries of the Snake River within Grand Teton NP may be modifying the adjacent riparian communities. Grand Teton NP still has remnants of past agricultural uses within those areas of the park added in the 1950s. Where agriculture existed near rivers, removal of floodplain vegetation may still be evident as the floodplains recover. Recreational use of riparian areas has been found to leave them vulnerable to over-use and degradation (Johnson and Carothers, 1982). Although limits on use of streamside areas may occur in some of the GRYN parks, BICA is established as a recreation area and potential heavy use along the Big Horn Lake margins may have deleterious effects. Effects of campers and day hikers on riparian vegetation along small mountain streams often are locally evident in Yellowstone and Grand Teton NPs.

Biological Stresssors. Ungulate grazing in riparian areas may disrupt the reproductive cycle of riparian trees such as cottonwoods, whose broad-leaved seedlings and saplings are extremely desirable forage. Removal of reproductive shoots also diminishes reproductive potential of willows (Kay 1994). Heavy ungulate use, both wild and domestic, of floodplains and riparian areas may greatly reduce riparian ground cover, destabilize streambanks, and increase sediment loads to streams (Patten 1968, Armour et al., 1991; Elmore, 1992; NRC 2002). Wild ungulate use in areas of Yellowstone NP, for example, the northern range, and Grand Teton NP, has altered the cover and structure of the riparian community (Singer et al. 1994, Singer 1996, Keigley 1997).
Beaver activity, although a normal component of riverine ecosystems in the GRYN parks, under specific conditions may be considered an ecosystem stressor. While beavers usually alter streams when occupying dam sites, or modify riparian vegetation whether housed in ponds behind dams or in stream banks, their absence may result in water table declines and associated long-term alteration or loss of riparian vegetation. Conversely, over-population of beavers in any reach of a river may cause major alterations of riparian vegetation through excessive harvesting of riparian woody plants. Several areas of the GRYN, for example, streams in the northern range of YNP, once supported extensive beaver populations but these are now absent (Bailey 1930, Wright and Thompson 1935, Jonas 1955). Also, continued beaver trapping outside the parks maintained low populations. Recently, however, beaver populations have dramatically increased in several areas of the GRYN parks. This recovery may ultimately result in “over-population” of beavers in some areas because many areas that once were suitable for beaver habitat in the region are no longer suitable for beaver population expansion because of unacceptable consequences of beaver activities in most areas of human habitation.

Non-native Species As Stressors. Introduction of non-native species has greatly altered the West’s riparian ecosystems and has become a major management issue in all three GRYN parks. Grazing and altered hydrology often favor the survival of introduced species (e.g., tamarisk) and allows thriving non-natives to displace native species. Russian-olive and tamarisk are two nonnative species that have greatly altered western riparian communities (Brock, 1984; Shafroth et al., 1995). Not only have they altered the communities they have invaded, they are difficult to remove. For example, tamarisk can repeatedly resprout after fire, cutting, or browsing, and it survives in very wet, very dry, or very salty soils (Gladwin and Roelle, 1998; Smith et al., 1998). An example of major tamarisk invasion in these parks is the exposed lake bed in BICA where the Big Horn River enters the park. Here tamarisk has developed a dense cover of young invasive woody plants. Extended inundation may be the only way to eliminate this extensive stand of tamarisk. Herbaceous non-natives are also becoming prevalent in many riparian areas creating dense ground cover that competes with native species, increases fuel for fires, and may be enhanced by grazing (Stromberg and Chew, 1997). All the parks are now contending with increasing cover of nonnative herbaceous plants. This has become a sufficiently important issue that the Biennial Science Conference in Yellowstone NP in 2001 (ref) emphasized this issue.

Climate Fluctuation as a Stressor. Climatic fluctuations over the past century have resulted in changes in local watershed hydrology which directly affect the condition of riverine and riparian systems. Long-term droughts not only reduce stream flows but diminish groundwater supplies, lowering water tables which are critical sources of water for riparian phreatophytic plants (Stromberg et al. 1996, Shafroth et al. 2000). Human accelerated climate change may create more erratic climatic fluctuations and could potentially produce extended droughts, much longer than that of the 1930s and similar to the 30-50 year droughts of 300 years ago. Riparian communities within the GRYN parks will respond relatively quickly to extended drought periods, reducing cover to only those areas that can maintain a shallow water table. These areas will be immediately adjacent to shallow bedrock streams and along margins of larger rivers where low flows may support alluvial groundwater. Climatic change and drought in the northern Rockies region will affect all three GRYN parks. Vegetation that is dependent on supplemental water, such as riparian vegetation, may be more altered by these changing conditions than upland vegetation.

Cumulative Effects of Stressors. Riparian ecosystem condition reflects the cumulative effects of all activities that influence watershed hydrology and thus may be an important indicator of changing environmental conditions within the GRYN parks. Multiple resource uses on mountains and in valleys have modified the quantity and quality of water entering rivers. This is true for BICA, as the headwaters of the Big Horn River are used for many forms of resource extraction, ranching and agriculture often with release of stream contaminants. Sometimes the results of land use can be subtle, while in other cases, downstream impacts on riparian ecosystems can be dramatic. Timber harvest may result in larger and flashier floods which carry increased sediment. Leaving a buffer zone may help reduce sedimentation rates and provide for continued ecological interactions between streams and riparian vegetation (Kauffman, 1988).

APPLICATION TO GREATER YELLOWSTONE NETWORK PARKS

Riverine and riparian systems within the three GRYN parks are influenced by many of the same stressors. The conceptual models illustrate the linkages between the many stressors (Figures 1-5). Although there may be many stressors that influence riverine and riparian systems in the parks, the conceptual model applies only a few that are known to potentially significantly alter these systems. As discussed above, stressors that influence riparian systems and that should be addressed in any inventory and monitoring program include (1) altered hydrology, (2) altered channel morphology, (3) climatic changes, especially droughts, (4) ungulate utilization of the riparian zone, (5) exotic plants, and (6) recreation. The discussion illustrates the importance of these stressors to each park but does not apply them specifically to park units. The importance to a park depends on extent and magnitude of a particular stressor. For example, altered hydrology is not a primary stressor in Yellowstone NP, but it plays and important role along the mainstem of the Snake River in Grand Teton NP, and is the primary stressor for the main water course and lake in BICA. Ungulates, on the other hand, may not be important in BICA along the river and lake, but are important locally in YNP and GTNP. BICA, on the other hand, may have ungulate herbivory issues in the uplands.

The conceptual model(s) show linkages among stressor and how they relate to dynamics of components of the riverine/riparian ecosystem. Following the flow of connected processes, it is possible to end up with a limited set of potential indicators that, if monitored, will offer evidence of changing watershed and river conditions within each park. Each park has been geographically divided into watershed units (HUC units) for the purpose of addressing variability across the landscape of the parks. Within the GRYN parks there are several riparian vegetation community types, some may occur in all parks while others may be specific to one or two parks, a consequence of geographic and environmental diversity. Table 1 presents riparian community types that occur within GRYN parks and identifies within HUC unit for each park those environmental threats or stressors that potentially may have an impact on longterm survival and condition of the riparian community. Eight different riparian vegetation community types are presented. Some of these relate to seral stages in riparian vegetation development and maturation, for example, gravel bar/river edge riparian communities up to mature cottonwood communities. Some riparian communities also relate to geographic locations, such as large river margins, lake shores, small mountain streams, or broad valley wetted-sediment

deposits. The list of riparian community types is simplified for application to the whole GRYN. If expanded based on diversity within community type, the variability would create hundreds of types. For example, twenty four species of willow are found in the northern range of YNP and these produce a diverse set of willow communities based upon diverse environmental drivers (YNP 1997).
To allow comparisons across community types, a brief description follows:

A. Gravel bar/edge wetlands: this community type is found on point bars and the edges of rivers where flood disturbance is frequent. In most cases the vegetation cover includes herbaceous pioneer species, but young woody riparian species like *Salix exigua* and *Populus spp*. may also be present. In most cases the vegetation cover is sparse.

B. Herbaceous meadow: the community type may occur in broad alluvial valleys where the river is downcut and few woody plants are present. Herbaceous species are predominantly wetland sedge and grass species. Wetland forbs also may be present.

C. Willow/shrub: this is a diverse community because of the potential number of willows that may be present throughout the GRYN. The community is dominated by shrub willows and occurs on the edge of streams, adjacent floodplains, wet alluvial flats and along seeps where groundwater is shallow. Some may be short willows (e.g., wolf willow), while some willow/shrub communities have tall willows (e.g., xxx). Other shrubs may be present with willows such as alder (Alnus spp.) in moist areas or shrubby cinquefoil (*Potentilla fruticosa*) in drier areas. In most cases, except where heavy browsing has reduced cover, aerial cover of this community is high.

D. Cottonwood: this community type, usually found in mid to lower elevations within the GRYN, is dominated by mature cottonwoods and may have some cottonwood recruitment under the canopy or in adjacent floodplain and point bar areas. There is little understory of other woody plants. This type of community may be found in areas with heavy browsing pressure, or in relatively sterile gravel or cobbled areas where cottonwood has established and has resisted scour when it occurs, but other woody plants either never established or were scoured away by high magnitude floods.

E. Cottonwood/willow/shrub: this community type found in mid to lower elevations in GRYN represents a mature cottonwood community with a well established understory of shrubs, often willows, and herbaceous ground cover. These usually are undisturbed sites with no deficiency of shallow groundwater.

F. Conifer/willow/shrub: this community type is more typically found along mid to higher elevation streams that have limited overbank scour. The conifer overstory represents mesic upland species growing near the stream, whereas willow and shrubs such as alder are more typically riparian and phreatophytic.

G. Lake shore: this community type could be represented by several of those above but also may include true wetlands where saturated sediment occurs along the lake margin. Willows may grow along stable lake shores whereas gravel bar type communities may be common along fluctuating lakes. Mid to higher elevation lakes may have conifer communities growing along the shoreline.

H. Riparian exotics (dominant): this community type occurs in highly disturbed areas or where hydrological controls are greatly altered from the norm. Nearly pure stands of tamarisk represent this type of community which often occurs in moist sediment upstream and at tributaries mouths of lakes with fluctuating levels. Altered downstream hydrology below dams also often creates riparian communities dominated by extensive stands of exotic species. Communities dominated by herbaceous exotic species (often noxious weeds) may occur on floodplain areas following a high magnitude, overbank, scouring flood.

Stressors that play an important part in each park differ, except perhaps for climate change and drought stress. Riparian communities in YNP, especially in the northern range, are greatly influenced by ungulate herbivory. GTNP has altered hydrology of the Snake River as a major issue, but it also has herbivory problems along some streams within the park. Primary stressors of riparian condition in BICA are altered hydrology and invasion of non-native riparian species. Table 1 summarizes the similarities and differences among the parks and the HUC units within the parks. Because riverine/riparian systems are linear and cover only a small percentage of the landscape, comparisons by watershed units within each park may be difficult; however, different conditions within each watershed, especially if they are some distance apart, might allow identification of different responses of riparian communities to similar environmental stressors.

POTENTIAL INDICATORS

Several indicators related to riverine and riparian ecosystems can be identified from the conceptual model and the discussion above. Some indicators may be stressors or other non- "outcome" parameters, but the best may be an outcome parameter that functions as an integrator of several processes.

A. *Riparian condition* is one indicator, in actuality an index, that includes several riparian community parameters and channel geomorphic parameters. Riparian ecosystems are integrators of hydrogeomorphic conditions as well as local land use processes. Riparian condition includes metrics of horizontal and vertical vegetation structure, vegetation diversity and channel stability. The U.S. Forest Service and BLM have developed an index, Proper Functioning Condition (PFC), that attempts to address these parameters but it is subjective and includes little biological information. A modified version of PFC may be an appropriate index to use for "riparian condition".

B. *Channel geomorphological metrics* may also be a useful indicator of the condition of riverine and riparian systems. The ratio of channel width to depth and channel sinuosity in relation to floodplain type can be combined to develop a channel index that would indicate whether the channel is be changed from the "expected" geomorphic conditions.

C. *Riparian avian community structure* may be used as an indicator of riparian condition. Species diversity of riparian avian communities, including presence and/or absence of certain species that have been identified as species commonly found in "healthy" or "degraded" riparian vegetation, can be used as a surrogate of riparian condition, including linear connectivity of riparian patches along a river.

D. A biological stressor, *exotic plants*, may also be a useful indicator of riparian vegetation condition. Increasing presence of exotic plant species has greatly altered many riparian systems in the West. A degraded riparian community may be altered primarily because of the presence of exotic species. If a relationship between altered condition and abundance of exotic species can be established, cover and diversity of exotic plant species in the riparian zone may be a useful longterm indicator.

E. *Aquatic biota*, that is macroinvertebrates and/or fish populations, often indicate the geomorphology of a channel, the bedload materials, flow velocities at various stages as well as water quality. For general riverine and riparian conditions, aquatic biota may not be the best indicator, but if a combination of physical and chemical qualities need to be evaluated, aquatic biota may be a useful indicator. This indicator applies more to the river or lake systems of the GRYN parks and is discussed in more detail in that section.

Measurement of any of the above indicators would be done at randomly selected locations along reaches of rivers of interest. For lakes shores, randomly selected locations along a shore would be used in place of reach locations along a river. For the various parks, rivers of different sizes (orders) would be identified and long-term monitoring stations would be established.

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APPENDIX J. Conceptual models (box and arrow) from Jean et al. 2003.

Figure 8. Box-and-arrow conceptual model (Lake).

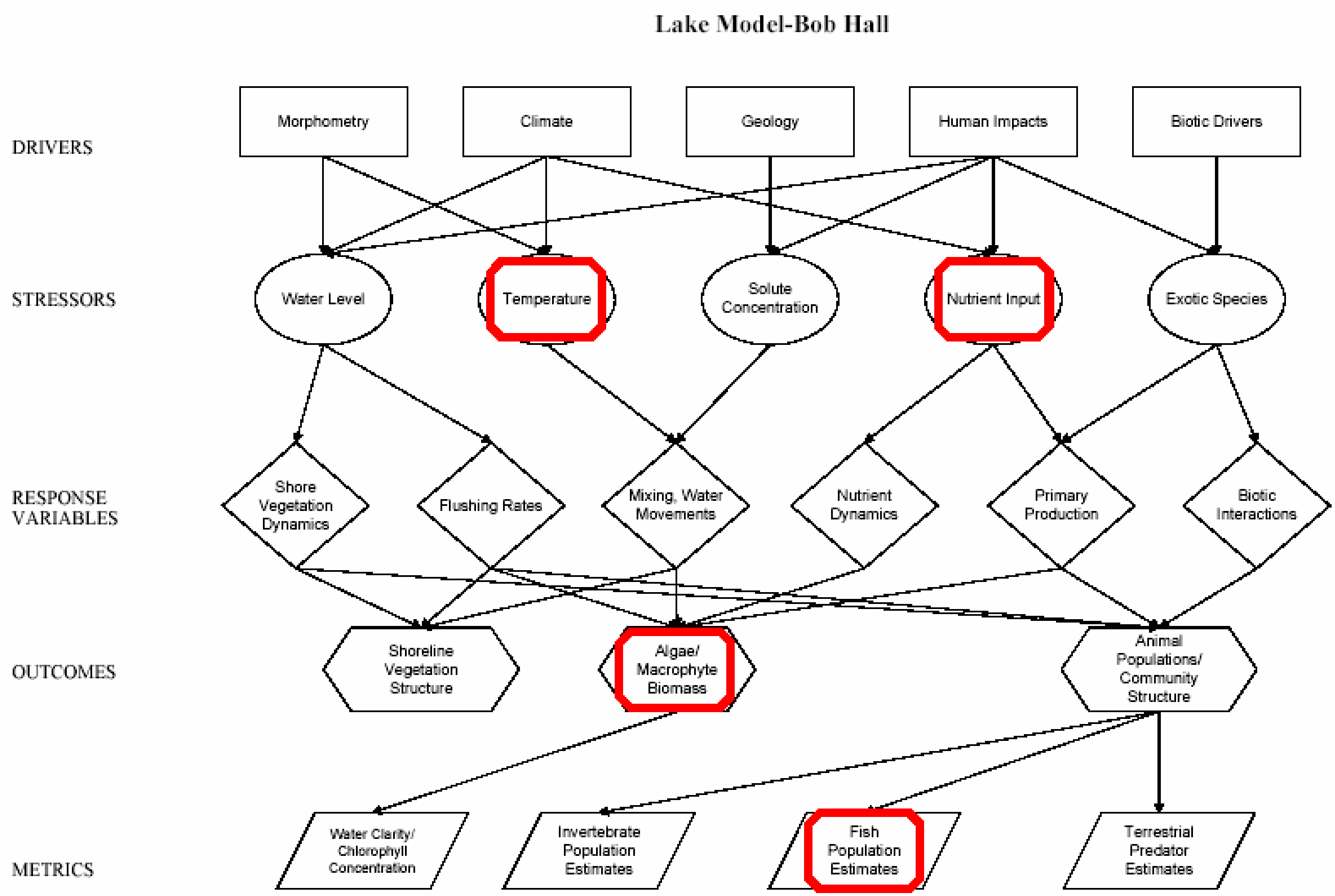


Figure 9. Box-and-arrow conceptual model (River).

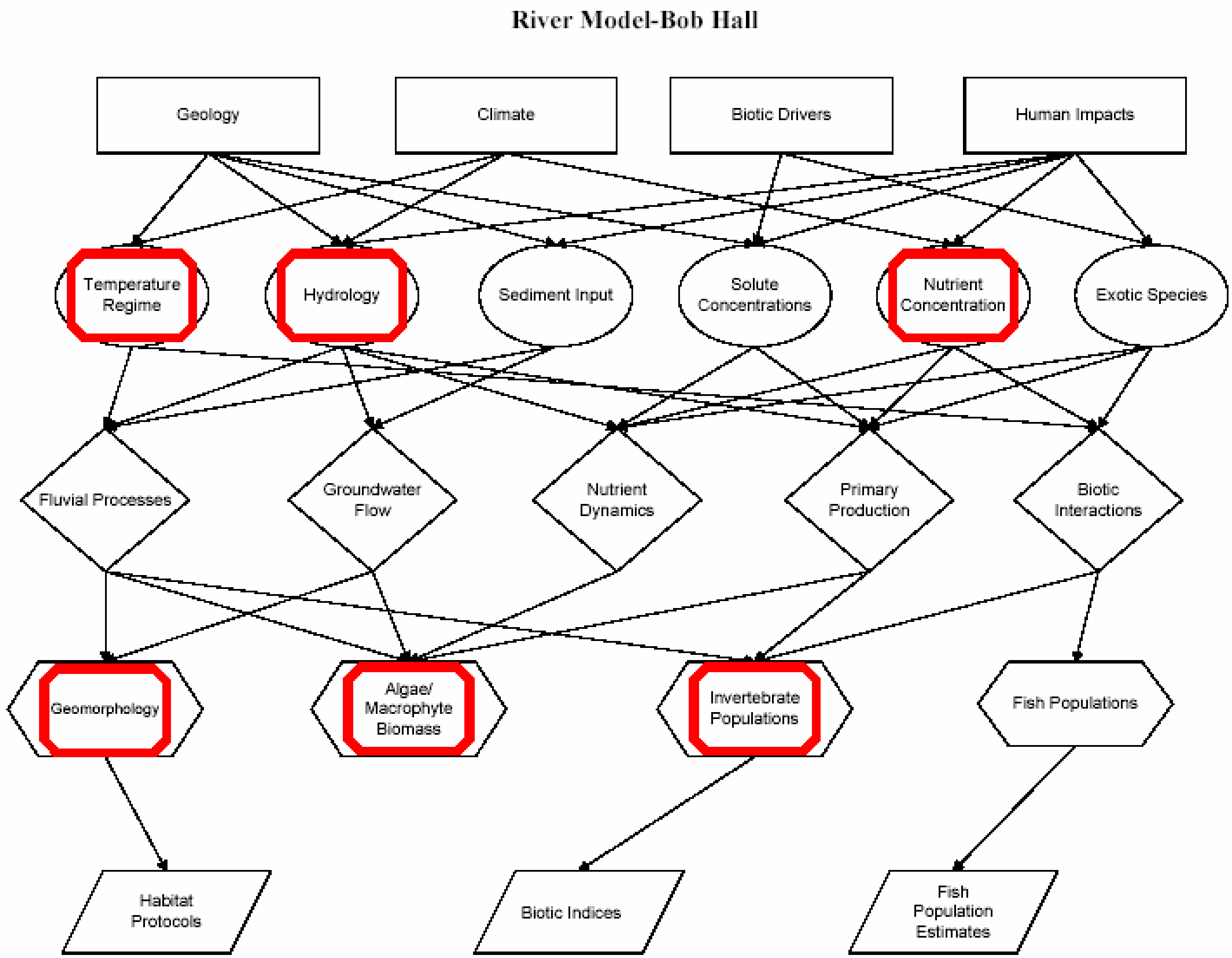


Figure 10. Box-and-arrow conceptual model (Riparian).

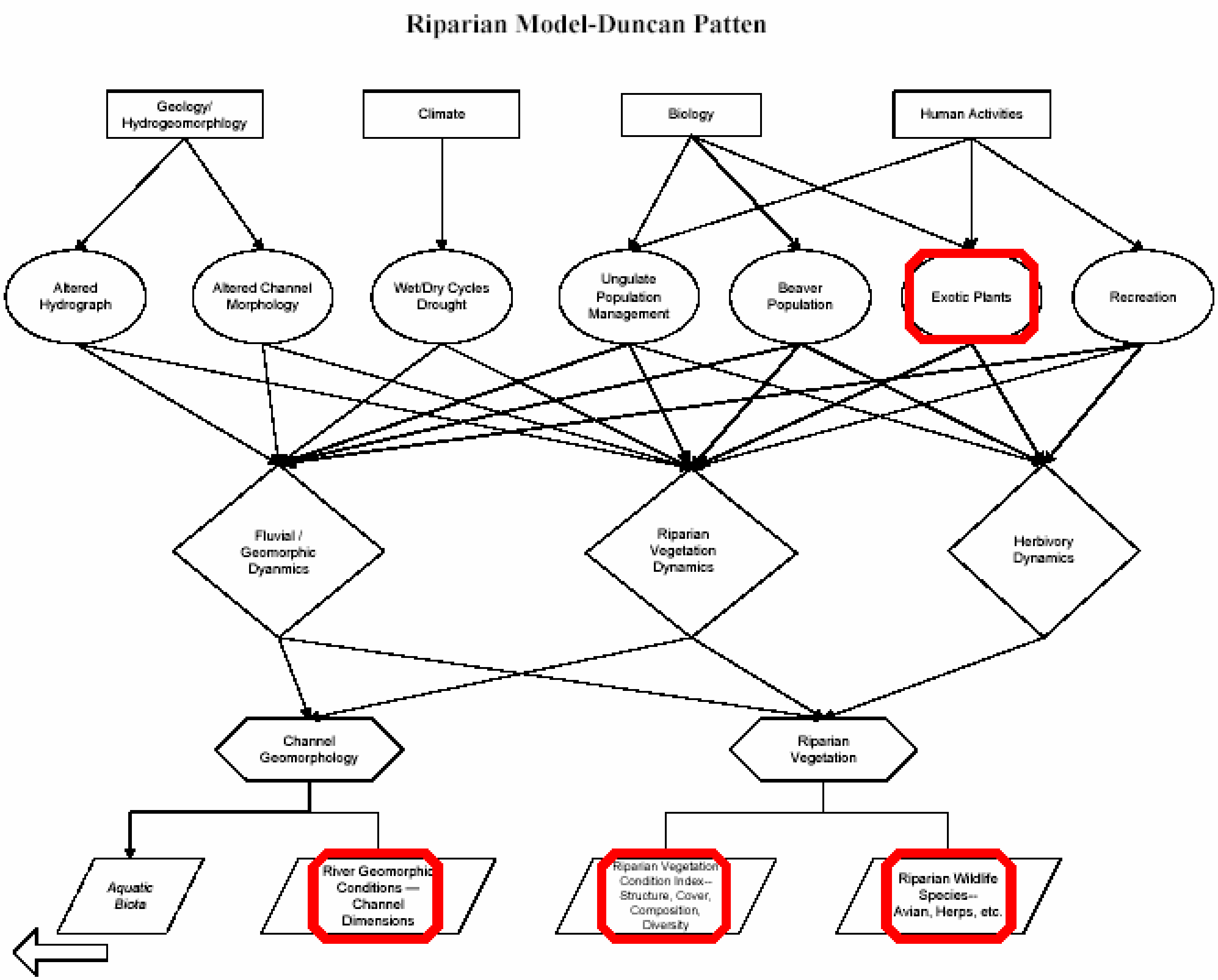
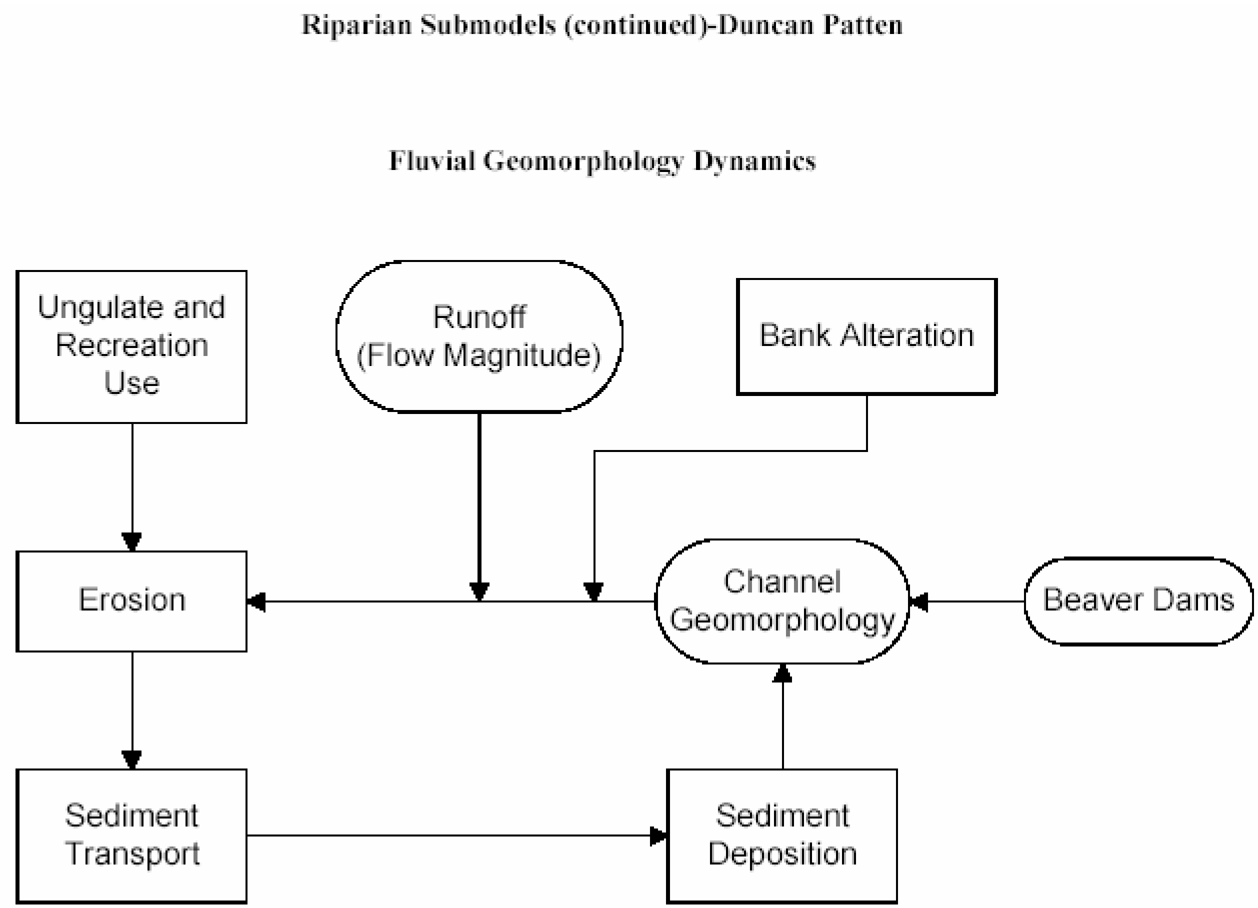


Figure 11. Box-and-arrow sub-model (Riparian).



APPENDIX K. GRYN’s 44 selected vital signs (water quality related in red).

Table 12. Technical Committee's recommended list of 44 vital signs for the GRYN (from Jean et al. 2003).

Resource/ ecosystem domain	Selected vital signs
Aquatic	Watershed budgets
	Continuous water temperature
	Groundwater quantity and quality
	Reservoir elevation
	River invertebrate assemblages
	Springs and seeps distribution and hydrology
	Stream flow
	Water chemistry
Aquatic Biotic	Algal species composition and biomass
	Escherichia coli
	Exotic aquatic community structure and composition
	Native community structure, composition, stability and genetic integrity
Atmospheric	Atmospheric deposition of nitrogen, sulfur and all major anions and cations (including wet and dry deposition)
	Change in visibility deciviews
Climatic	Basic climatological measurements
	Glacial retreat or advance
Geologic (geothermal)	Earthquake activity
	Geothermal feature abundance and distribution
	Geothermal water chemistry
	Heat flow/chloride flux
	Soil structure and stability (includes cryptogamic crusts)
	Stream sediment transport
Human	Land-use change and habitat fragmentation
	Levels of backcountry day use
	Levels of backcountry overnight use
	Oversnow vehicles emissions
	Soundscapes
	Visitor use levels
Terrestrial Biotic	Amphibian occurrence
	Beaver presence and distribution
	Browse effects on riparian woody vegetation
	Communities of concern (riparian, shrub-steppe, aspen, and alpine)
	Exotic plant species abundance and distribution
	Fire, fuels and carbon storage
	Forest insect and disease
	Land bird distribution and abundance
	Land-cover classification
	Large carnivore population distribution and abundance
	Meso-carnivore population presence and distribution
	Native insect diversity and distribution in riparian and mesic meadows
	Selected sensitive bird species abundance, distribution and productivity
	Ungulate population distribution and abundance
	Vertebrate diseases
	Whitebark pine decline

APPENDIX L. Peer Review Comments

GRYN Phase II Water Quality Monitoring Plan
Reviewer Comment Table
12/19/03

Reviewer Name: **Jeff Arnold**			**Affiliation: Yellowstone National Park** **Mailing Address:** **Email:**	
Section #	**Page #**	**Line #**	**Comment or Suggested Wording**	**Cite** **(if applicable)**
	10		First sentence within the YNP grouping. The wording states YNP encompasses **a watershed**, but in fact several watersheds are found within the park contributing to both the Columbia and Missouri drainage's. This needs to be reworded to reflect that. Same paragraph under YNP grouping nine lines from the top. Sentence begins with "The 670 mile Yellowstone River......" I would remove this sentence entirely.	
	17		Under GRTE heading, the second sentence beginning with "In 2001, the NPS WRD..." This sentence is referring to BICA and not GRTE and should be placed under the BICA grouping.	

GRYN Phase II Water Quality Monitoring Plan
Reviewer Comment Table
12/19/03

Reviewer Name: Myron Brooks and staff			**Affiliation:** U. S. Geological Survey, Water Resources Division District Chief, Water Resources Division 2617 E Lincolnway, Ste B Cheyenne, WY 82001	
Section #	**Page #**	**Line #**	**Comment or Suggested Wording**	**Cite (if applicable)**
Answers to peer review questions			Q: Does the plan adequately describe why parks are monitoring "vital signs"? A: YES; Q: Does the plan answer the question "who is interested in the information provided by monitoring and why"? A: YES: Q: Does the plan adequately describe the water resources in each of the network parks? Are impaired or pristine water adequately identified? A: YES; Q: Does the plan adequately identify the sources of pollution and other suspect stressors for each of the network parks? A: YES. Q: Does the plan adequately describe historical/existing water quality monitoring efforts in each of the network parks? A: YES. Q: Does the plan adequately describe how the monitoring objectives for impaired waters were developed? Are these objectives sufficient to address monitoring needs? A: YES.	
II	10	14	Consider additional reference for ground water resources: USGS WRIR 95-4204 "Water Resources of Teton County, Wyoming, exclusive of Yellowstone National park"	
II	13	16-7	Statement that "natural snowmelt hydrographs no longer exist" is incorrect. Many small low-order streams still are unaffected by diversions, reservoirs, etc. In addition, larger streams (Shoshone, shell cr. Owl cr.) have substantial mileage where a measured annul hydrograph	
II	18	8-12	USGS monitors wells once per year, not aware of WY-DEQ involvement	
II	24	22-24	Suggested re-wording "Fish tissue analysis for metals, when performed multiple times over a several year period can provide a time-integrated measure of stream metals contamination."	
	39	1-9	TSS data will not be directly comparable with historical suspended sediment concentration	USGS

IV			(SCC) data collected by USGS	OSW&OQW Tech Memo 2001.03; USGS WRIR 00-4191
VI	41-43		Numerous section headings have no accompanying text	
I and IV	4 and 35		Draft monitoring strategy indicates use of USGS protocols for chemistry. Water chemistry vital sign includes Kjeldahl Nitrogen, a parameter USGS is phasing out.	

GRYN Phase II Water Quality Monitoring Plan
Reviewer Comment Table
12/19/03

Reviewer Name: **Don Campbell**			**Affiliation: USGS** **Mailing Address:** **Email:**	
Section #	**Page #**	**Line #**	**Comment or Suggested Wording**	**Cite** **(if applicable)**
Answers to Peer Review Questions			Q: Does the plan adequately describe why parks are monitoring "vital signs"? A: YES; Q: Does the plan answer the question "who is interested in the information provided by monitoring and why"? A: YES: Q: Does the plan adequately describe the water resources in each of the network parks? Are impaired or pristine water adequately identified? A: Generally, yes. One resource that was not mentioned was small ponds that are habitat for amphibians. Given declines of amphibians worldwide and possible links to water quality this would seem to merit some attention. Possibly ponds are included in some other category such as wetlands? Q: Does the plan adequately identify the sources of pollution and other suspect stressors for each of the network parks? A: This is done fairly well early in the text but is not as consistent in the discussion of specific vital signs on p. 30-40 (esp. notable were few references to potential problems from the large amounts of domestic waste transported and treated in YELL.) Toxic metals and organic compounds are not given adequate attention. There are large potential sources of these in agricultural runoff as well as mining and energy development occurs in watersheds upstream of the parks. Recent studies highlight the potential for both local and long-range atmospheric transport of mercury and semivolatile organic contaminants (eg. Pesticides, PCB's, flame retardants, etc.), and the tendency for these compounds to accumulate in cold environments at high latitude and high altitude. For more info: http://www2.nature.nps.gov/air/aqmon/air_toxics/ Q: Does the plan adequately describe historical/existing water quality monitoring efforts in each of the network parks? A: Yes, pretty well. One additional reference: D.D. Gulley and M. Parker, A limnological survey of 70 small lakes and ponds in Grand Teton NP, Dept. Zoology and Physiology, University of Wyoming, Sept. 1985.	

			Q: Does the plan adequately describe how the monitoring objectives for impaired waters were developed? Are these objectives sufficient to address monitoring needs? A: Yes. However, I think that the differences in all aspects of monitoring for impaired vs. other waters may be understated. Regulatory processes outside the control of the NPS will drive monitoring objectives and strategies for impaired waters, and future changes in required monitoring could consume substantial resources that might have originally been intended for monitoring the "pristine" waters that distinguish the National Parks from most of the rest of the country's water resources. The GRYN should consider means to protect monitoring resources allocated to pristine waters from future "reprogramming", otherwise the vital signs monitoring could gradually morph into a simple regulatory compliance monitoring program while failing to address broader issues of ecosystem health.	
General Comments			The document is generally well-written. The hierarchy of heading notation was not intuitive however and could be improved by changing fonts/ indents/ underlines. Strongly recommend analyzing for all majors, nutrients and DOC on most samples, because there is a wealth of information regarding hydrologic and biogeochemical processes in this data that can also help explain nutrient and contaminant data. I would suggest emphasizing the the link between deposition, continuous flow, and complete chemistry measurements to get budgets. Better to do a few sites well (and long-term!) than to have bits and pieces of data from many sites. Use nested watershed approach if possible to examine scaling/ landscape/ land use issues.	
	ix	Figure 5 caption	Can you cite database or annual report here and elsewhere?	
	9	General	Need to have maps of sufficient detail to find the features discussed in this section. Also include maps showing upstream watersheds including land use and point sources.	
	9	GRTE	This is most recent renovation? Earth/ concrete construction? (Not timber crib!) Ht. of dam/ range in water level?	
	14	Para#3, last sent.	Yes or no?	
	15	End of para on atmos. Depo.	Need to discuss atmos. dep of Toxic,esp. Hg and pesticides. Hg deposition measured in high elevations of Colorado incl. ROMO is equivalent to that in upper midwest and northeast. There is MDN collector in YELL. High conc. of NH4+ in snowpack may indicate agricultural sources of pollution that could also be source of pesticide contamination.	
	16	Hist & current mon.	These sections are inconsistent regarding inclusion of various data types. For example, snow distribution is included for GRTE. If such a broad definition is being used, then NADP, MDN and snowpack chemistry data for YELL and GRTE should be included. Likewise, need to be	

			consistent regarding inclusion of physical data like streamflow.	
	26	Stressors	Some air pollution stressors actually operate on global scale. (Eg. Hg and toxics)	
	28	Table 2	Place in same order in table and text.	
	31	Flow/discharge	Discuss use of continuous measurements at stream gages.	
	31	Water chemistry	Consider lumping parameters into major ions and nutrients. Strongly recommend analyzing for all majors and DOC on most samples, because there is a wealth of information regarding hydrologic and biogeochemical processes in this data that can also help explain nutrient and contaminant data.	
	32	Specific conductivity	Mention availability of sensors for continuous monitoring of SpCond. These can greatly improve load estimates and watershed budgets.	
	35	Nitrogen, Kjeldahl	Mention also newer methods for analysis of total N, which yields organic N by subtraction of NH4 and NO3	
	36	Trace metals/toxics	This section weak! Need to discuss sources, toxicity, etc. of metals incl. Hg and organics incl. pesticides. Need to include potential atmospheric sources. Also use of trace metals for source attribution from diff. pollution sources.	
	38	Watershed budgets	Watershed biogeochemical budgets consist of simply measuring inputs and outputs, usually of major ions and nutrients. Many of these other measurements are part of intensive studies but are not necessary for a budget study. Establishing basic biogeochemical budgets would provide a foundation that could lead to collection of these other types of data to test hypotheses about driving processes.	
	41	Selecting a chemical lab	Recognize that one size does not fit all and there are methods developed specifically for needs like sampling in remote locations and analysis of very dilute waters.	
	53	Table 3	Use of quotes around "impaired", "in the park's perspective", "Perceived to be" etc. make most of this sound very weak.	
	89	Middle of last para	Does not incorporate knowledge of atmospheric deposition maps (Nanus) developed from NADP and snowpack data (Ingersoll and others). There is also long-term monitoring data from lakes in the Wind River Range done by USDA-FS	
	91	Water temp	Water temp is cheap to collect but reams of data require lots of human resources to manage, QA, archive, etc. These costs must be considered when comparing to other types of data collection.	
	91	Surface hydrology	Smaller lakes and streams will be more sensitive to changes in climate and less confounded by land use issues.	

GRYN Phase II Water Quality Monitoring Plan
Reviewer Comment Table
12/19/03

Reviewer Name: Sue Consolo Murphy			**Affiliation: GRTE** Mailing Address: Email:	
Section #	**Page #**	**Line #**	**Comment or Suggested Wording**	**Cite** (if applicable)
Answers to peer review questions			Q: Does the plan adequately describe why parks are monitoring "vital signs"? A: YES; Q: Does the plan answer the question "who is interested in the information provided by monitoring and why"? A: YES: Q: Does the plan adequately describe the water resources in each of the network parks? Are impaired or pristine water adequately identified? A: YES; I seriously question YELL's useof the language under their waters as "thepark perceives these as impaired" – Heart Lake, Madison/Gallatin/Firehole/Snake Rivers, etc. when GRTE has none and these are not 303d "impaired". Q: Does the plan adequately identify the sources of pollution and other suspect stressors for each of the network parks? A: See #3 above; if there are issues in YELL waters they were not adequately identified to justify to me the use of this term. Q: Does the plan adequately describe historical/existing water quality monitoring efforts in each of the network parks? A: Generally. I missed an explanation of so many red dots a GRTE and YELL maps for historic monitoring sites – but it may have been there and I missed in skimming. Q: Does the plan adequately describe how the monitoring objectives for impaired waters were developed? Are these objectives sufficient to address monitoring needs? A: YES.	
	14	3	Why not mention exotic trout in lake as a threat? I see that as important, perhaps more – than effects of native ungulates on vegetation.	
	14	8-10	Yes, but I hate to lump cattle w/native ungulates. I also dislike the use of this term in a park context. Population levels (sometimes high ones) are elastic. I prefer to acknowledge that native spp. May have high or intense levels of grazing, but "over" population implies a judgment that there's some "right" level. I question that.	
	20	Yellowstone	This blows me away – potentially threatened I can accept: "impaired" I think is a BAD term	Dabney-v-SUWA

		NP	that is 1)mot justifiably explained here and 2) Should not be used lightly (if at all) in view of the recent legal language use of "impairment".	case, Utah
	44	Literature cited	Usually the first author is last name first, isn't it? You're inconsistent in whether you capitalize or don't all words in titles . . . and in conference titles	CBE, JWM manuals/guidelines

GRYN Phase II Water Quality Monitoring Plan
Reviewer Comment Table
12/19/03

Reviewer Name: Robert O. Hall, Jr			**Affiliation:** Department of Zoology and Physiology University of Wyoming	
Section #	**Page #**	**Line #**	**Comment or Suggested Wording**	**Cite** **(if applicable)**
Peer Review Questions			Q: Does the plan adequately describe why parks are monitoring "vital signs"? A: YES; Q: Does the plan answer the question "who is interested in the information provided by monitoring and why"? A: YES: Q: Does the plan adequately describe the water resources in each of the network parks? Are impaired or pristine water adequately identified? A: YES, I think this section was good. Q: Does the plan adequately identify the sources of pollution and other suspect stressors for each of the network parks? A: The plan is missing Lake trout from Yellowstone Lake, for which there are data that show that Lake trout predate is most likely decreasing cutthroat trout abundance. I would also say that future invasions are a stressor, even though those species have not yet arrived. Also Kelly Warm Springs is highly invaded by aquarium fish such as convict cichlids. Q: Does the plan adequately describe historical/existing water quality monitoring efforts in each of the network parks? A: YES. There have been lots of one-off studies of aquatic ecosystems in the parks, that while not exactly monitoring per se, they provide data than can be used to develop future plans or look back. For example, nutrient chemistry and algal assemblage data by Kilham and colleagues of Jackson, Lewis and Yellowstone lakes. We have lots of NO3 data from Teton Park streams. There have been several studies of aquatic invertebrates in both parks that may help provide a baseline for future tests.	
Vital Signs			Flow/discharge: In addition to measuring discharge, it would be best to record stage at these locations to get continuous records, but maybe not necessary outside the areas where USGS is already doing this? DO page 32. Some natural streams will have DO less than 5 mg/L (at night) if they receive lots of groundwater or have particularly high respiration rates. Because our altitude is so high, we	

			can get lower DO than the rest of the country near sea level, where these regs are derived. Also, I am not sure that daytime DO is all that useful, as the potential for low DO is in the middle of the night. Cl can also increase in freshwater, particularly lakes from road salt. This is a big problem in the Northeast PO4 of page 35. I would mention that although we want to know how much PO4 is present, the technique we use, the Molybdate-blue method, measures SRP, and that is much larger than the SRP pool, and is in fact somewhat undefined. Or else just say we measure SRP which is as close as we can get to biologically available inorganic P River invertebrate assemblages. I think that this is a very important vital sign, yet its description is much shorter than man others that are less important (e.g. Conductivity or chlorophyll). It may be putting in there what the methods are (e.g. WY IBI, O/E etc) and how the data will be used. In many ways this techniques is better than the physical measurements. I like the description on how the bugs can integrate over time. Watershed budgets. I would put in some language that a budget integrates physical (e.g. hydrology, temp etc.) with biological processes (e.g. vegetation dynamics, soil microbes, stream processing). I though that there was going to be a fish population (e.g. cutthroat trout) vital sign? Yellowstone has an incredible record of spawning density of trout for Clear Creek and elsewhere, and those data could be very useful in assessing overall health of Yellowstone lake and surrounding rivers and terrestrial habitat.	

GRYN Phase II Water Quality Monitoring Plan
Reviewer Comment Table
12/19/03

Reviewer Name: **Bill Jackson**			**Affiliation: NPS-WRD** **Mailing Address:1201 Oakridge Dr, Ste. 250, Ft. Colins, CO 80525-5596** **Email: bill_Jackson@nps.gov**	
Section #	**Page #**	**Line #**	**Comment or Suggested Wording**	**Cite** **(if applicable)**
Responses to peer review questions			Q: Does the plan adequately describe why parks are monitoring "vital signs"? A: YES; Q: Does the plan answer the question "who is interested in the information provided by monitoring and why"? A: YES: Q: Does the plan adequately describe the water resources in each of the network parks? Are impaired or pristine water adequately identified? A: YES; Q: Does the plan adequately identify the sources of pollution and other suspect stressors for each of the network parks? A: YES. Q: Does the plan adequately describe historical/existing water quality monitoring efforts in each of the network parks? A: YES. Q: Does the plan adequately describe how the monitoring objectives for impaired waters were developed? Are these objectives sufficient to address monitoring needs? A: YES, however objectives for non-impaired (pristine) waters also needed	
General			This is an extremely well-written report that, with one exception discussed below, meets all the expectations of the Phase II reports for Water Quality Monitoring. A number of elements in the report were particularly well expressed, and include: Development of goals that adequately combine both state and Federal CWA requirements, management needs, and the goals of the Vital Signs Monitoring Process Identification of the most significant park water bodies Development of general recommendations to guide the development of monitoring objectives, including recommendations to use existing established protocols, and to conduct initial rounds	

			of high-frequency sampling to better quantify variability issues Identification of management stressors Statements of Desired Future Conditions for park waters Development of monitoring questions/objectives for impaired waters Excellent concurrent development of GIS and data management programs The GRYN approach to the design of its water quality monitoring program is also commendable for its high levels of "hands-on" park involvement as well as the inclusion of external input from both the science and regulatory communities. The most significant report deficiency is the absence of specific monitoring objectives for pristine park waters, where the management goal is to maintain existing water quality, and the monitoring goal is to identify any deterioration in water quality. Development of specific monitoring objectives is an expectation of the Phase II report (Chapter 3). This deficiency must be adequately planned and budgeted for in the Network's FY04 Annual Work Plan, and should be accomplished early in the fiscal year. Based upon follow-up correspondence from the Network, it seems that a good set of monitoring objectives for "other waters important to the purposes of the parks" are drafted and under review by the Network.	
	Pg iii	Para 1, 3rd sent.	Probably more accurate to say that the report "…summarizes the activities undertaken to select and prioritize vital signs used for monitoring the state of the parks' water quality" (not "water resources").	
	Pgs 12-13		It would be nice if some of the information scattered in the appendicles could be pulled together here (or elsewhere in the report). There's a lot of good information in the appendices, but it's scattered and forces the reader to relate the various tables to each other. A table listing each water body of interest, known parameter exceedances for each waterbody of interest, potential land uses that might be causing exceedances (on impaired waterbodies), and other potential threats and their potential indicators (both impaired and pristine waters) would really help pull some of this information together for the reader. Appendix H summarizes standards, but they aren't related to specific waterbodies. Likewise, Appendix B identifies exceedances, but they are not tied to specific water bodies or potential stressors of interest to this program. Appendix A identifies threats, but doesn't always relate them to potential monitoring parameters. Etc.	
	Pg 21-22	Last para on 21 and 1st	(This comment expands on the one above). I think it would be good to expand upon/complete this discussion and the tables in Appendix G. The tables in Appendix G list water bodies that should be monitored and identifies potential vital signs, but for GRTE does not include the	

		para on 22	"how to monitor" column. Likewise, the reason to monitor is not identified for GRTE or YELL. This section of the report is real good stuff, and would logically lead to a prioritization and selection of the specific objects of the Networks monitoring program design. Any expanding of this material (maybe further drawing from Woods/Corbin) would strengthen this report.	
	30		The discussion of the Flow/Discharge vital sign: I would add that discharge is a real important co-variable in explaining water quality variability. Relationships between water quality measures and discharge can often be used to remove (to some degree) the influence of discharge on variability over time.	
	31		The discussion of the water chemistry vital sign. For water chemistry to be a useful vital sign, there needs to be an association between individual parameters and the potential stressors of interest. It would be good to have a table that not only lists some of these chemical constituents and other parameters, but also identifies various land uses (stressors) of interest to the Network for which individual parameters are indicators.	
	39		The discussion of the stream sediment transport vital sign: Channel and riparian condition, while probably not direct water quality vital signs, are important ecosystem vital signs that relate directly to the sediment transport question, as well as to the aquatic habitat question. There was a good discussion of this in the Appendix. Hopefully the water quality program is an advocate to the VS Monitoring Program for channel and riparian condition as an important vital sign for aquatic systems affected by grazing or upper watershed land uses that result in increased erosion (I did not see this vital sign listed in Appendix K, Table 12). In cases where sediment transport is a driving issue, it would be good to coordinate WQ monitoring with channel and/or riparian monitoring.	
	Appendices E & F		Excellent GIS layers!	
Summary comment			In summary, this is a well done report. The only substantive shortcoming is the omission of specific monitoring objectives for pristine waters. There is a lot of excellent information in the Appendices that, if pulled together, would greatly enhance the utility of this report in Phase III planning. Thanks for the opportunity to review this report!	

GRYN Phase II Water Quality Monitoring Plan
Reviewer Comment Table
12/19/03

Reviewer Name: Cathie Jean			**Affiliation: GRYN** **Mailing Address:** **Email:**	
Section #	**Page #**	**Line #**	**Comment or Suggested Wording**	**Cite** **(if applicable)**
Appendices E&F			I concentrated my comments on the tables and map figures. More than anything, the network needs to have a good handle on locations of current monitoring. Who is doing what, when, where and why. I am looking at Appendix E and F and wondering why two appendices.. and if either accurately tells me where the current monitoring is and what should be the data source(s) .. that we can count to be correct. I even went back to the water chemistry technical note and yet... it's different too.	
Appendix E			Appendix E. Location of current and historic water quality monitoring stations Figures 2,3,4 are deceiving in that if the data came from Woods and Corbin, then the maps do not include any of the GRTE backcountry monitoring or the YELL permanent stations. The data source for these maps is actually STORET (2001?). Given that Woods and Corbin downloaded STORET and did not add any data.. I have a hard time giving them credit for developing the database (they developed forms and made queries). The title should be left off the map (since you have a figure title that reads slightly different). The Yell map does not have a data source	
			Appendix F. Location of current monitoring stations in the GRYN and table of locations and parameters monitored Figures 5,6,7 do not match with what you have in the corresponding table 8. Is the table incomplete? Where are the YELL permanent stations? where are the stream guaging stations? Should the title read differently? There must be a better way to reference the shape file for these maps rather than personnel communication (doesn't that imply a telephone or in person call). When Chad tracked down the metadata for this shapefile, he learned that the file was not intended to be converted to a shape	

			file. The map has the data source as being USGS.. how did Robert Swanson get the YELL locations? Finally..shouldn't these appendices match with what you say is taking place in chapter 1 under current and historic monitoring? There should be a connection between the text, the table 8 and the maps.	
	16-19		• it should be task agreement, rather than cooperative agreement • what information did Woods & Corbin update that wasn't in the original reports for WRD? • the USGS 2003 web reference should read a web reference (location and date).. and then the data is good until 9/30/2002 • fecal coliform is not being regularly monitored at BICA	

GRYN Phase II Water Quality Monitoring Plan
Reviewer Comment Table
12/19/03

<table>
<tr><td colspan="3">Reviewer Name:
Dixon H. Landers Ph.D.</td><td>Affiliation: Senior Research Environmental Scientist (Limnology)
U. S. Environmental Protection Agency
National Health and Environmental Effects Research Laboratory
Western Ecology Division
200 SW 35th Street
Corvallis, Oregon, USA 97333</td><td></td></tr>
<tr><th>Section #</th><th>Page #</th><th>Line #</th><th>Comment or Suggested Wording</th><th>Cite
(if applicable)</th></tr>
<tr><td>Answers to peer review questions</td><td></td><td></td><td>Q: Does the plan adequately describe why parks are monitoring “vital signs”?
A: YES;
Q: Does the plan answer the question “who is interested in the information provided by monitoring and why”?
A: YES:
Q: Does the plan adequately describe the water resources in each of the network parks? Are impaired or pristine water adequately identified?
A: YES – to the extent that the extant data inform this question. Biases and uncertainties in the extant data are not discussed
Q: Does the plan adequately identify the sources of pollution and other suspect stressors for each of the network parks?
A: Generally, YES. Long range transport of pollutants and SOCs are generally NOT represented. For example, J. Blais is not listed in the reference list.
Q: Does the plan adequately describe historical/existing water quality monitoring efforts in each of the network parks?
A: YES, generally. See comment to #3 above.
Q: Does the plan adequately describe how the monitoring objectives for impaired waters were developed? Are these objectives sufficient to address monitoring needs?
A: YES, but more importantly the success of this monitoring effort depends on how they are interpreted in the ultimate design and upon management support over the long term of such a program.</td><td></td></tr>
<tr><td></td><td>21, last para.</td><td></td><td>1) When asking park personnel for which waterbodies should be monitored – there is no discussion of uniform criteria to be applied across the parks. This implies that this will be a totally subjective exercise that will lead to a subjective monitoring program design. 2) the selection of vital signs (i.e. indicators) also seems to be totally subjective. Shouldn’t this be</td><td></td></tr>
</table>

			based on some sort of sensitivity analysis rather than suggestions from NPS staff alone?	
	39, para 4		The framework approach to be taken in this monitoring program appears to be one of a probability sample from a defined target population. This seems to me to be the correct approach to take. How this will be achieved is fundamental to the results that will be derived from the program. The seven lines of text devoted to this cornerstone of the program are woefully inadequate and out of balance with the pages of text devoted to the 10 vital signs (indicators) that will form the core metrics. This should be remedied in revision and the framework, at a minimum, of the statistical design should be fully articulated.	
	40, Sec. V		Whether or not a robust sampling design can be crafted to meet stated objectives is only demonstrated by a resulting design. This document, by plan, does not go so far as fleshing out the design. Often this is a very painful process where a list of objectives, design elements and budget realities must be iteratively adjusted to achieve the final program design. Given this, I suggest that this incomplete version of the sampling design not be sent out for another review until it is totally fleshed out with all of the placeholder sections that are listed in Sections V, VI, VII, VIII, IX, X, XI and XII. Only after completing this vital part of the plan will reviewers be able to determine if the objectives and background information are faithfully reflected in the resulting design.	
General Comments			First, I would like to comment on the scope of this task. It is nearly impossible to pass judgment on an isolated component (i.e. Draft Phase II WQM Plan) of what surely will be a complex final document. Ideally, the final design of the plan to which the Phase II component contributes will be balanced with the available long term monitoring funds and a realistic (i. e. affordable and manageable) sub-set of the desired components of a final plan that are articulated herein. At this point in the process, the final design is unknown. Second, it is mentioned in the first sentence of the Executive Summary (page iii) that consistency in monitoring the long-term health of the nation's parks is an overarching goal of the I & M Networks. While it is not discussed in this document, and perhaps my comments are too late, it is my understanding that each of many NPS I&M Networks has the charge of designing and implementing their own monitoring program, independent of what other parks are doing. Based on my 20+ years of aquatic monitoring experience this will not achieve any sort of consistency at a national scale. If it is too late to address this in total, I ***strongly*** urge management to make sure that there is a consistent set of measurements and indicators measured in a consistent way among all I & M Networks so that direct comparisons can be made across all networks. This would greatly add to the utility of the I & M program. Finally, what follows are some general comments on the Phase II plan for GRYN followed by some specific comments. Generally, the document is well written and does a fine job of describing much of the science and monitoring data on which the final GRYN monitoring plan	

			will eventually be built. This portion of the overall plan focuses on impaired waters yet the definition of "impaired" is only implied for the first time (that I could find) on page 22, par. 2. When it is finally discussed it is explained to be driven by individual states as part of their listed 303(d) waters. This tells me that the states of WY and MT independently define the impaired systems that will form the domain or possibly the population of interest for this monitoring work. Given that neither state is at the forefront of water quality monitoring in the nation, this is a bit of a concern. Thus, the definition of impaired varies in some undefined way and there is no assurance that the definition is inclusive of all deserving systems. This is a problem that at least should be recognized in this document, if not solved. There is little apparent recognition in this document, as evidenced by the lack of articulation on the subject, of the level of resources and commitment it takes to determine the status and trends in monitored aquatic systems. Status and trends are stated repeatedly as the desired objective of the I & M program. Status can be determined only by either a census or a statistical sample of a defined population of aquatic systems of interest using appropriate indicators. Trends can only be determined by taking repeated measurements of indicators over time – in this case typically years/decades. The length of time required to detect a trend depends on the natural variability of the indicators and the degree of certainty desired with respect to the trend one is hoping to detect. Developing and implementing a monitoring system to detect trends requires a steadfast commitment by funding agencies to stay with a program for the long term. Moreover, sources of sampling and analytical variability (i.e. error) for which we have some control must be kept to a minimum over the long term. This will result in the cumulative error remaining as small as possible and it will then be dominated by the natural variability for which we have no control. These issues should be thoroughly addressed in revision. I think that it is the job of the authors of such a document to synthesize workshop input, where possible, and put forth a cohesive monitoring plan. There is a fatal trap in environmental monitoring when the designers try to be all things to all constituents or workshop participants. What this often means is that decisions have to be made – starting with winnowing down the suggestions from the workshops and making tough choices. This process appears not to have begun yet for this monitoring program. As an example, on page 21, par. 3, there is a shopping list of "questions to be answered" that includes a whole range of issues that are research studies onto themselves. Many of these suggestions imply developing cause and effect relationships. I most strongly encourage the designers of this monitoring program to determine what are the most important objectives and scientific questions that the program will be designed to answer, state them early in the document and stick to them as guiding design principles.	
In conclusion			In conclusion, it is almost impossible to evaluate the planning/background component of a monitoring design without knowing how this effort has been used to develop the final design. I have provided some comments that I hope will be useful in developing the final I &M design. I	

			think, in general, that the project is on the right track in that it has begun with accumulating a tremendous amount of guidance, opinion and data. How all of this information is distilled and synthesized into the design of the final monitoring program is where the magic happens and is the true test of the overall effort. Based on my experience, the bulk of the work lies ahead for the GRYN. It is not a trivial task from the scientific or administrative perspective. Scientists can design the almost perfect effort but will management have the will and resources, over the decades ahead, to stay the course financially and programmatically to achieve the results of detecting status and trends? Designing a program that will meet both scientific and management needs is really the issue yet to be addressed.	